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NCHRP Report 431

Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation

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Report 431

Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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FOREWORD

By Staff
Transportation Research Board

This report contains the findings of a study to develop methodologies for measuring the effects of congestion on the values highway users place on travel-time savings and predictability. The methodologies were used to generate values for factors for different degrees of congestion. The study also defines an approach for incorporating these factors in highway user-cost estimates. The contents of this report, therefore, will be of immediate interest to highway professionals responsible for planning, administering, and financing highway improvements, as well as those involved in highway operations, capacity, and traffic control. The report also will be of interest to those concerned with freight transportation issues as well as environmental, safety, and human performance issues.

A partnership of Hickling Lewis Brod, Inc. (now HLB Decision Economics, Inc.) in Silver Spring, Maryland, and the University of California at Irvine, was awarded a continuation contract to conduct NCHRP Project 2-18(2), "Validation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation." The research team conducted this research and wrote the report.

The report addresses two important aspects of travel time. First, do travelers and freight carriers place a premium on travel-time savings (or reduced delays) during periods of congestion? Second, is there a value placed on the predictability of travel times? The research concentrated on the value of travel time during periods when stop-and-go traffic occurs (i.e., "Levels of Service E and F").Under those conditions, congestion results not only in longer travel times but also makes travel time less predictable, both for passenger travel and freight shipments.

The research is based on the analysis of stated preference surveys developed specifically for this project—for both passengers and freight carriers. (The stated preference survey database for travelers is more robust than that for the freight carriers.) Statistical analyses of the stated preference survey database were used to develop a series of models, both simple and more sophisticated; these models are presented in tabular form in the report. The results of this research provide current values of passenger travel time; incorporating these research results into standard highway user-cost analysis requires segmentation of trips by purpose (work or non-work), household income, total trip time, and period (peak or off-peak).

Incorporating the costs associated with travel-time unreliability is more complicated. The report recommends that, until further studies are done, time savings during congested peak periods be monetized at the value of time multiplied by a mark-up factor reflecting the aversion to congested conditions, including their associated unreliability.

The report concludes that, although the results of the freight travel survey confirmed the importance of transit time, on-time shipment, and freight costs in shipping decisions, the survey failed to measure a significant value for changes in transit-time predictability. The report identifies the deficiencies in the freight travel survey that led to the inconclusive results and recommends further research to reduce these shortcomings.

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The authors also gratefully acknowledge the assistance of Karina Tury, formerly of the University of California at Irvine, and Anthony Fowkes of the University of Leeds, England, for their assistance in conducting the research presented here. Any errors and omissions are the responsibility of the authors and contributors alone.

VALUATION OF TRAVEL-TIME SAVINGS AND PREDICTABILITY IN CONGESTED CONDITIONS FOR HIGHWAY USER-COST ESTIMATION

SUMMARY

The report addresses two questions about the value of travel time. First, do travelers and freight carriers place a premium on travel-time savings (or reduced delays) during periods of heavy congestion? Second, is there a separate value placed on the predictability of travel times? In answering these questions, the report develops methodologies for measuring the effect of congestion on the values that highway users place on travel-time savings and predictability. The methodologies are used to generate values for travel-time savings and predictability. In addition, an approach for incorporating these factors in highway user-cost estimation is discussed.

The literature on the value of passenger travel time is extensive and well developed. Values of travel time have most often been determined by estimating mode choice models (logit, probit) and evaluating the marginal rates of substitution between the costs and travel times of the alternative models. Some studies have used route choice models. Another approach is to examine residential housing costs, the hypothesis being that people will pay more for housing locations that reduce their travel costs (especially for work trips).

The focus here, however, is the value of congested travel time (where congestion is defined as stop-and-go traffic at Levels of Service E and F). Congestion not only results in longer travel times but also makes travel time more unpredictable. There has been little research attempting to identify the difference in the values of congested versus uncongested travel time. Those few studies that have analyzed the difference suggest that congested travel time is valued more than uncongested travel time (i.e., there is a greater disutility or discomfort associated with congested travel conditions). Travel time under congested conditions is less predictable than other travel time so that the measured valuation of congested travel time will include both the discomfort of congestion and the unpredictability. The analysis in the report separates these two components.

Research attempting to place a value on the reliability of passenger travel time is relatively new. The adoption of stated preference techniques has provided a valuable tool for estimating this attribute. Reliability (or uncertainty) of travel time is usually measured by the standard deviation of travel time between any two points. Most empirical studies show that the standard deviation of travel time is a significant and negative attribute in the traveler's utility function. The value of both time and reliability also

vary across different groups of travelers. Business travelers and people commuting to work place a higher value on travel time and predictability than do individuals pursuing non-work-related travel.

Congestion also contributes to longer and more unpredictable travel times for freight shippers, as with passenger travel. This unpredictability can hinder just-in-time inventory management programs and even interrupt freight-dependent production processes. As a result, freight shippers are very likely to attach a dollar value to any increases in predictability that would help them avoid the costs associated with such problems. Studies have shown that the most important factors influencing choices in freight transportation include freight charges, value of commodity being shipped, loss and damage, transit time, and reliability.

PASSENGER SURVEY ANALYSIS

The SR 91 corridor in Orange and Riverside Counties in Southern California was selected as the basis for the passenger study. In order to create the database for modeling overall travel time and travel time reliability, a two-step stated preference survey process was developed and conducted. The first step involved a general transportation survey instrument from which traveler and trip characteristics in the SR 91 corridor could be profiled as a basis for developing a customized stated preference survey instrument, which was administered in the second step.

Step 1. In mid-1995, 2,500 surveys were sent to residents along the SR 91 corridor in Orange and Riverside counties in Southern California. The first 200 were a pilot test mailed on July 7, while the other 2,300 were the main survey mailed on November 15. In the case of the main survey, extensive follow-up was undertaken using reminder postcards and, if necessary, a duplicate survey instrument. The response was 53.9 percent.

Step 2. When the first completed survey instrument (the transportation survey) was received at the project office, the customized stated preference survey questionnaire was mailed. This was followed by the same follow-up procedure of reminder cards and, if necessary, a duplicate questionnaire. The response rate on the second part was 71.1 percent.

The stated preference questionnaire asked people to choose among situations in which they have to trade off total travel time, the fraction of travel time in congested conditions, and trip cost. Other questions asked them to choose among situations with different travel times, costs, and degrees of travel-time predictability—the latter being described in terms of five hypothetical arrival times that might occur on 5 different days. Using the survey data, separate models for calculating the effect of congestion on the values of travel time and travel-time predictability are developed. The models are estimated using logit choice estimation techniques.

In the case of the effect of congestion on the value of travel time, the most suitable model includes average total travel time, fraction of time spent in congested conditions, income of respondent, and the monetary cost of the trip. All coefficients have the expected sign and are significant. Including the income variable allows for the calculation of travel time values at different income levels. As shown in Table S-1, for an household annual income of $15,000, the value of travel time is $2.64 an hour; for an income level of $55,000, the travel time value is $5.34 an hour; and an income level of $95,000 has a corresponding travel time value of $8.05 an hour. These values are within the range found in the literature, albeit somewhat at the lower end.

From the same model, Table S-2 gives the estimated cost that travelers assign to shifting 1 min of uncongested travel to 1 min of congested travel. As shown in Table S-2,

TABLE S-1 Estimated values of total travel time

Household Annual Income ($000s)	Value of Total Travel Time ($/hour)
15	2.64
35	3.99
55	5.34
75	6.70
95	8.05

the cost declines with journey time and journey length; this is to be expected given that the amount of time spent in congested (stop-and-go) traffic declines as a percentage of total trip time as trip length increases. For a trip of 10 min, shifting 1 min of travel time from uncongested to congested conditions is equivalent to adding $0.76 to the trip cost. This value drops to $0.13 for a trip with a travel time of 60 min.

The second type of model constructed from the stated preference passenger survey is used to generate values for travel-time reliability. Several models with varying degrees of sophistication were estimated. However, the basic result remains the same: *travelers place a value on travel-time reliability.* In the most basic model, the standard deviation of travel time is used to measure reliability. A value of $0.21 per minute (or $12.60 per hour) of standard deviation is calculated for journeys of average length. When the $12.60 value of reliability is compared with the overall value of travel time (of about $5.30 at the median income level), it is evident that travelers value improved reliability more than twice as much as overall travel time improvements.

Other models distinguishing between low- and high-income groups and between work and non-work trips are also estimated. Here, high income is defined as household income greater that $45,000 per year. As shown in Table S-3, reliability is valued more among higher income travelers and on work trips than among lower income travelers and on non-work trips.

When scheduling costs are explicitly accounted for, the variable measuring the standard deviation of travel time (i.e., travel-time reliability) no longer has explana-

TABLE S-2 Estimated value (cost) of shifting 1 min from uncongested to congested travel

Total Travel Time (minutes)	Cost Increment ($ per minute)
10	0.79
15	0.52
26	0.30
30	0.26
45	0.17
60	0.13

TABLE S-3 Estimated values of reliability

Trip Type and Income	Value of Reliability ($ per minute of std. dev.)
Work trip, higher income	0.26
Work trip, lower income	0.22
Non-work trip, higher income	0.21
Non-work trip, lower income	0.17

tory power. It is therefore concluded that scheduling costs account for all the aversion to travel-time uncertainty. Therefore, in models with a fully specified set of scheduling costs, it is unnecessary to add an additional cost for unreliability of travel.

FREIGHT SURVEY ANALYSIS

A similar analytical approach was used for freight carriers, although on a much smaller scale. Information was collected through a stated preference survey. The stated preference experiments are designed to evaluate how the carrier would trade off freight costs and improvements in transit-time reliability in selecting how early to depart from the origin for a typical shipment that has a desired arrival time at the destination. Again, models are constructed to assess the importance of transit-time reliability in shipping decisions.

Compared with passenger travel (where the results are robust), the empirical results are somewhat inconclusive on the freight side. Several factors contribute to the weakness of the freight side results, but a small sample size is probably the most important. Of the 168 freight carriers selected, 20 telephone interviews were completed. While the results did confirm the importance of transit time and freight costs in shipping decisions, they failed to measure a significant value for transit-time predictability. Carriers on average value savings in transit time at $144.22 to $192.83 per hour and savings in late schedule delays at $371.33 per hour.

Examining the findings reported above in the context of overall trucking costs indicates that reliability ranks high among the attributes of highway performance considered by the trucking industry. Whereas the estimated value of transit-time savings represents about 30 percent of overall average hourly trucking expenses (measured at the mid-point of the estimated range), the value of late schedule delays represents fully two-thirds the value of overall average hourly trucking expenses. As in the case of automobile travelers, truckers value time savings in congested conditions more than twice as highly as overall travel time savings.

Several factors contribute to the relatively weak findings of the freight analysis:

- The sample consisted of only twenty carriers.
- The characteristics of carriers were not controlled.
- Respondents expressed difficulties in understanding the cost variable, distribution of schedule delays, and hypothetical experiments.
- The methodology did not use simulations to adjust variable values.

In addition, the model could be improved by grounding it more firmly in a theoretical model of carrier behavior.

IMPLICATIONS FOR PROJECT DESIGN AND EVALUATION

The implications of the findings reported above are profound for the design and evaluation of highway improvements in relation to both passenger and freight traffic. Cost-benefit analysis tools in use today cannot distinguish between the value of time savings in congested versus noncongested conditions. This means that economic criteria for project design and project selection fail to account for a fundamental value distinction made by both passenger and freight highway users. The results of this study imply that considerable improvements to cost-benefit analysis could be achieved by carefully measuring the travel-time savings under both congested and uncongested conditions and by measuring the changes in predictability of travel times under congested conditions. As an interim measure, the study provides a straightforward method of adapting existing cost-benefit analysis tools. The method entails segmenting traffic forecasts by time of day and applying a "mark-up" factor to value of time assumptions that apply during periods of congestion. Based on the results reported in this study, the recommended mark-up factor is 2.5.

CHAPTER 1

INTRODUCTION

Estimating the time and delay-related benefits of building highway facilities is typically based on evaluations of the average travel-time savings that users of the facility will receive. However, when facilities are congested, other delay-related factors may be more important than savings in average travel time. In particular, the reliability of the system can be crucial, since this introduces uncertainties about arriving at one's destination at a predictable time. Penalties for late arrival may be greater than the benefits of reduced travel times. These penalties can represent actual loss of income (e.g., hourly workers may have wages deducted) or non-pecuniary effects that can lead to eventual loss of income (e.g., diminished prospects for promotion because of frequent late arrivals).

Freight shippers face a similar situation. The importance of travel-time reliability is becoming more pronounced as many manufacturers adopt "just-in-time" manufacturing processes and other schedule-dependent inventory, assembly, and distribution logistics. By timing the shipments of parts to arrive just in time, the manufacturer can significantly reduce inventory costs. An unreliable transportation system makes it much more difficult to implement this sort of system or to derive the maximum potential gains in productivity from its use.

1.1 PURPOSE OF THE REPORT

This report provides insight on two important aspects of travel time. First, do travelers and freight carriers place a premium on travel-time savings (or reduced delays) during periods of congestion? Second, is there a value placed on the predictability of travel times? In answering these questions, the report develops methodologies for measuring the effect of congestion on the values that highway users place on travel-time savings and predictability. The methodologies are used to generate values for travel-time savings and predictability. In addition, an approach for incorporating these factors in highway user-cost estimation is also discussed.

The literature on the value of passenger travel time is extensive and well developed. Values of travel time have most often been determined by estimating mode choice models (e.g., logit and probit) and evaluating the marginal rates of substitution between the costs and travel times of the alternative modes. Some studies have used route choice models. Another approach is to examine residential housing costs with the hypothesis being that people will pay more for housing locations that reduce their travel costs (especially for work trips).

The focus here, however, is on the value of congested travel time. Congestion not only results in longer travel times but also makes travel time more unpredictable. There has been little research attempting to identify the difference in the values of congested versus uncongested travel time. Those few studies that have analyzed the difference suggest that congested travel time is valued more than uncongested travel time (i.e., there is a greater disutility or discomfort associated with congested travel conditions). Travel time under congested conditions is less predictable than other travel time. Thus the measured valuation of congested travel time will include both the discomfort of congestion and the unpredictability caused by congestion. This report describes analyses that separate these two components so that the discomfort applies to congested conditions whether or not they are recurrent, whereas the aversion to unpredictability applies specifically to congested conditions that vary from day to day.

Research attempting to place a value on the reliability of passenger travel time is relatively new. The adoption of stated preference techniques has provided a valuable tool for estimating this attribute. Reliability (or uncertainty) of travel time is usually measured by the standard deviation of travel time between any two points. Most empirical studies show that the standard deviation of travel times is a significant and negative attribute in the traveler's utility function. Both the value of time and reliability also change across different groups of travelers. Business travelers and people commuting to work place a higher value on travel time and predictability than do individuals engaged in non-work-related travel.

As with passenger travel, congestion also contributes to longer and more unpredictable travel times for freight shippers. This unpredictability can hinder just-in-time inventory management programs and even interrupt freight-dependent production processes. As a result, freight shippers are very likely to attach a dollar value to any increases in predictability that would help them avoid the costs associated with unreliable travel times. Studies have shown that the most important factors influencing choices in freight transportation include freight charges, value of commodity being shipped, loss and damage, and transit time and reliability.

1.2 DESIGN OF THE STUDY

The study design is relatively straightforward. Information has been collected for passenger and freight traffic through survey instruments.

In mid-1995, 2,500 surveys were sent to residents along the SR 91 corridor in Orange and Riverside counties in Southern California. Addresses were obtained from a commercial firm and limited to zip codes adjacent to the corridor. The first 200 were a pilot test mailed on July 7; the other 2,300 were the main survey mailed on November 15. In the case of the main survey, extensive follow-up was undertaken. Reminder postcards were sent out after 1 week and again after 2 weeks; if no response was received by the end of the 3rd week, a duplicate survey instrument was sent, again followed by weekly reminder postcards.

When the first completed survey instrument (the transportation survey) was received at the project office, the customized stated preference survey questionnaire was mailed within 1 day. This was followed by the same follow-up procedure of reminder cards and, if necessary, a duplicate questionnaire. Ultimately, 1348 completed and usable transportation surveys and 959 completed and usable stated preference surveys were received. (About 6 percent of the non-responses were the result of bad addresses and other miscellaneous factors.) These figures represent response rates of 53.9 percent and 71.1 percent on the two survey parts.

The stated preference passenger travel questionnaire asked people to choose among situations in which they had to trade off total travel time, the fraction of travel time in congested conditions, and trip cost. Using the survey data, separate models for calculating the effect of congestion on the values of travel time and travel-time predictability were developed. The models were estimated using logit choice estimation techniques.

A similar analytical approach was used for freight carriers, although on a much smaller scale. Information was collected through a stated preference survey. The stated preference experiments were designed from the carrier's point of view. In particular, they were designed to evaluate how the carrier would trade off freight costs and improvements in transit-time reliability in selecting how early to depart from the origin for a typical shipment that has a desired arrival time at the destination. Again, models were constructed to assess the importance of transit-time reliability in shipping decisions.

Compared with passenger travel, the empirical results are somewhat inconclusive on the freight side. Several factors may contribute to the weakness of the freight side results, but a small sample size probably accounts for most of the unfavorable findings. Nevertheless, the freight carrier analysis did confirm the importance of transit time and freight costs in shipping decisions. In addition, the analysis identified areas where more research and information would be useful. Several recommendations for improving the freight analysis are also put forward.

1.3 ORGANIZATION OF THE REPORT

The body of the report consists of Chapters 2 through 7. Chapter 2 provides a review of literature on the value of travel time, the value of reliability, and the effect of congestion on these values. Both theoretical and empirical contributions are discussed. Chapter 3 presents the methodology used in the passenger travel surveys. Chapter 4 summarizes the results of the passenger transportation survey. Chapter 5 provides the analysis of the stated preference passenger survey. The effect of congestion on the value of time and the effect of travel-time uncertainty on travel behavior are analyzed in Chapter 5. The freight survey findings and analysis are presented in Chapter 6. Chapter 7 provides an overview of incorporating congested travel-time values and predictability in highway user-cost estimation. Background and supporting materials are provided as appendixes.

CHAPTER 2

LITERATURE REVIEW

The purpose of the literature review was to identify, review, and synthesize the results of value-of-time research pertaining to the effects of congestion on the value of travel-time savings and predictability. This was done for both passenger and freight travel. The review is organized as follows. First, some of the conclusions reached by other reviews of the value of time (especially with respect to any results that value time for different income groups, different trip purposes, peak versus off-peak work travel, and different modes) are discussed. Then the literature on travel-time reliability is examined. This consists of brief discussion of some of the theoretical contributions and then a discussion of the few empirical results that have been produced. The literature on reliability considerations for freight shippers is then discussed. Finally, those few cases where reliability considerations have been incorporated into planning practices are discussed.

2.1 VALUATION OF TRAVEL TIME

The literature on the value of passenger travel time is extensive and well developed. Therefore, the conclusions reached by comprehensive reviews of the value of time literature are summarized and then, after a general discussion of methods and problems with travel-time valuation, results related to valuation of congested travel time are discussed.

Values of travel time have most often been determined by estimating mode choice models and evaluating the marginal rates of substitution between the costs and travel times of the alternative modes. Some studies have used route choice models. Another approach is to examine residential housing costs (the hypothesis being that people will pay more for housing locations that reduce their travel costs [especially for work trips]).

Hensher (1978) provides a comprehensive review of the literature and identifies many key questions for future research. He discusses several approaches to valuing commuter travel time and outlines some of the advantages of adopting stated preference methods to collect survey data, based partly on a critique of revealed preference techniques. For example, the relationship between how travelers perceive attributes and how they are reported is unclear, as is the relationship to attribute measurement done by the researcher. Habit formation is another problem, especially for repetitive commute journeys. Hensher discusses some early stated preference (or willingness-to-pay) studies that attempted to avoid some of these problems (e.g., Lee and Dalvi, 1969; Hensher, 1976; and Heggie, 1976).

Bruzelius (1979) also reviews the empirical literature on the value of time. Although he criticizes several studies as using poor data and suspect techniques and oversimplifying assumptions, he does offer some generalizations based on the literature. He states that walking and waiting time are valued from 2 to 3 times more than in-vehicle time and that in-vehicle time for work trips is between 20 to 30 percent of the wage rate. He cites Quarmby's (1967) evidence that the ratio of in-vehicle time to the wage rate is generally constant across a wide range of wage levels. For leisure travel, he finds mixed evidence about its valuation relative to work travel.

More recent reviews have suggested a consensus that the value of time for work trips is about 50 percent of the wage rate on average (Small, 1992; Waters, 1992) and that it varies with income or wage rate but not necessarily proportionally.

Stopher (1976) discusses some of the methodological problems with estimating values of travel time. In particular, he expresses concern that if important travel characteristics are not controlled for, then the value of other attributes will be explained by the value of travel time. One example is comfort and convenience, which may have some association with trip time. If a particular journey is not comfortable, time may be valued at a higher level than if the trip is made under more comfortable conditions. Mohring et al. (1987) provide an analysis taking these into account. This analysis suggests that congested versus uncongested travel should be estimated separately. Travel time predictability may also be hidden in the values of travel time estimated in models that do not explicitly take it into account.

Despite this observation, little research has attempted to identify the difference in valuations of congested versus uncongested travel time. Those few studies that have analyzed the difference suggest that time is valued higher under congested conditions. Train (1976) divides auto travel time into a congested and a free-flow component. He finds that the congested travel time coefficient is about 30 percent larger than the free-flow travel time. Bradley et al. (1986) also found valuations about 30 percent larger in built-up areas or congested conditions compared with free-flow conditions in the United Kingdom. Bates et al. (1987) finds that congested travel time values are 33 percent larger than in uncongested traffic.

Hendrickson and Plank (1984) analyze data from a travel survey in Pittsburgh, Pennsylvania. They use a disaggregate model of mode and departure time choice to determine separate values for in-vehicle, congested, and transit wait times. They find values of $1.71, $4.50, and $17.14 per hour respectively. They also have results for walking time, late time, and early time. Unfortunately, coefficients for free-flow and congested travel times were not significant, so the results from this study are inconclusive about how congested versus uncongested travel is valued.

Hensher et al. (1989) performed a stated preference survey of route choice for a tolled versus an untolled route. They measured time values for different types of travelers (e.g., commuters [broken down by those using privately owned vehicles and those using employer-owned vehicles]), travel as part of work, and non-work travel. They could not find any significant difference between total travel time and travel delay (i.e., congested time), except for those who commute using employer-owned vehicles. This could perhaps represent a proxy for higher income groups, who are more likely to have vehicles provided by their employers.

The MVA Consultancy et al. (1987) report on the value of travel-time savings for the U. K. Department of Transport. This report includes a detailed analysis of the value of travel time for different modes and for different trip purposes and provides convincing results that there is variation with the level of income. The MVA report, drawing on Bradley et al. (1986) and other work for that project, also suggests that values of travel time in congestion may be 40 percent higher than in free-flow traffic. The definition of "congestion" is necessarily imprecise because of variation in how it is used in the underlying studies.

Gunn (1991) reports surprising results for a study conducted in the Netherlands. For business travelers and commuters, congestion increases the willingness to pay for travel-time reductions, as expected (i.e., the value of congested travel time is higher than that of uncongested travel time). For other travelers, however, willingness to pay is actually lower in congested conditions. This may be a result of these travelers having greater flexibility in choosing departure times. By way of contrast, the MVA Consultancy and ITS Leeds (1992) work on value of time in the Netherlands found that congested value of time is between 1.5 to 3.9 times higher than in free-flow conditions.

Guttman (1979) reports estimates that the value of time during peak hours is $5.17 per hour as opposed to an off-peak value of $1.91 per hour. He attributes this to the greater uncertainty of travel times during the peak. He also finds that the average value of time for commuters traveling every day is $1.91 per hour versus $2.95 per hour for those who travel less frequently but at least once a month. The implication is that daily commuters have better information and can thus better estimate delays; the differential between variance on different routes is presumed to be smaller for frequent commuters.

Guttman's speculation that the greater valuation of congested travel time is accounted for by greater variation or uncertainty of travel times is plausible. The problem is that travel time under congested conditions is usually less predictable than other travel time; so unless predictability is explicitly measured and included, the measured valuation of congested travel time will include both the discomfort of congestion and the unpredictability. Bates (1990) estimates that about 15 percent of the average value of time as conventionally measured in London may represent a valuation not of travel time itself, but of the unreliability usually associated with slower speeds. These observations point out the need to separate these two components—a major goal of this project.

2.2 VALUING THE RELIABILITY OF PASSENGER TRAVEL

Research attempting to place a value on the reliability of travel time is relatively new. The adoption of stated preference techniques has provided a valuable tool for estimating this attribute. The following sections discuss some of the theoretical contributions on how travelers react to travel-time uncertainty and provide a review of some recent empirical results.

2.2.1 Theoretical Contributions

The variability of travel time has been defined by Bates et al. (1987) as consisting of three distinct effects. First, seasonal and day-to-day variations cause *inter-day variability* in travel times (these result from such factors as demand fluctuations, accidents, road construction, and weather conditions). Second, *inter-period variability* reflects the effect of different departure times and the consequent changes in congestion that an individual will face. Third, *inter-vehicle variability* results from personal driving styles and the behavior of traffic signals along a given route. (Bates et al. note that locating a parking spot can also add to the travel-time uncertainty associated with a given trip.)

An early theoretical contribution on traveler reactions to uncertain travel times is that of Gaver (1968). Gaver developed a framework based on utility maximization to demonstrate that commuters (or other travelers with a desired arrival time) will depart with a "head start" time (i.e., they anticipate the variance in travel times and plan their departure a little earlier than if travel times were certain). This is similar to the "safety margin" hypothesis proposed by Knight (1974). Polak (1987) adds a concave transformation to Gaver's linear utility function in order to represent risk aversion, while Bates (1990) also develops a model to account for shifts to earlier departure times as variance increases.

Jackson and Jucker (1981) assume that travelers trade off the expected travel time against travel-time variance (or standard deviation). This theory ignores any scheduling costs and does not imply any particular functional form for the relationship between cost and unreliability. Senna (1994) combines the expected utility approach of Polak (1987) with Jackson and Jucker's (1981) mean-variance approach. Senna (1994) defines expected utility in terms of a combined function of travel times and travel-time variance, thereby allowing risk aversion (or proneness) to be measured. Empirically he finds that commuters with fixed arrival times are risk prone (i.e., they prefer a greater variability in travel times). He attributes this to the absence of lateness penalties. Another possibility, however, is that his modeling approach misses the effects of scheduling costs.

Small (1982) establishes empirically that scheduling costs play a major role in the timing of commuter departures. Let t_w be the official work start time. If a commuter leaves home at time t_h and the travel time on a particular day is T, then the commuter will arrive early if $t_h + T < t_w$ and late if $t_h + T > t_w$. Small (1982) defines variables to measure how early or late this is: schedule delay early (*SDE*) is defined as $t_w - (t_h + T)$ if the commuter is early, and zero otherwise; while schedule delay late (*SDL*) is $(t_h + T) - t_w$ if the commuter is late and zero otherwise. This scheduling cost function, C_s, is postulated to be as follows:

$$C_s = \alpha T + \beta(SDE) + \gamma(SDL) + \theta D_L \qquad (1)$$

where D_L is equal to 1 when $SDL \geq 0$ and 0 otherwise. The coefficient α is the cost of travel time, and β and γ are the costs per minute of arriving early and late, respectively, and θ is an additional discrete lateness penalty.

The theoretical model of Noland and Small (1995) is an extension of Gaver (1968) and Polak (1987) which adds two features of Small (1982): a discrete lateness penalty (θ in Equation 1) and changing levels of congestion. It thereby accounts for the fact that alternative departure times face a different level of congestion. This model allows a full decomposition of the various cost elements of the morning commute which are the expected cost of schedule delay, lateness, and travel time. This gives the following relationship:

$$EC_S = \alpha E(T) + \beta E(SDE) + \gamma E(SDL) + \theta P_L \qquad (2)$$

where $E(T)$ is the expected travel time, $E(SDE)$ is the expected schedule delay early, $E(SDL)$ is the expected schedule delay late, and $P_L \equiv E(D_L)$ is the lateness probability. Given a specific probability distribution for the uncertain component of travel time T, this formulation enables the analyst to predict the head-start time that the traveler will choose and the resulting value of expected scheduling cost. Increased variability in travel time T will increase this expected cost because it will increase one or more of the last three terms, the exact mix depending on how the traveler responds in altering the head-start time. Noland and Small (1995) provide analytical results for two probability distributions—the uniform and the exponential.

2.2.2 Empirical Contributions

Empirical work on measuring traveler responses to reliability has been slow to develop. Prashker (1979) performs a factor analysis that identifies the importance of travel reliability to travelers from their answers to questions about various travel characteristics that matter to them. Much of the other early work is speculative or uses crude proxy measures to account for reliability. Abkowitz (1981) defines an expected loss function to represent traveler perceptions of the loss from early or late arrival. He does not find any statistical significance to the loss associated with uncertainty and attributes this to possible inaccuracies in the available data; however, it could also result from a misspecification of the expected loss functions, whose empirical parameters were postulated rather than measured. Abu-Eisheh and Mannering (1987) estimate a departure time and route choice model, including a variable for the percent of coordinated traffic signals, which they interpret as a proxy for travel-time variance. They obtain a negative coefficient on this variable indicating a preference for reduced travel-time variance. Pells (1987) obtained stated preference estimates of "late" and "slack" (early) time.

Mahmassani and various associates have simulated time of day departure choices over a period of several weeks using stated preference or laboratory data collected from actual commuters (see Mahmassani and Herman, 1989; Mahmassani and Stephan, 1988; Mahmassani and Tong, 1986; and Chang and Mahmassani, 1988). These data are used to fit dynamic behavioral models which, together with a traffic simulation model, generate new choices and conditions for each day. These papers focus on day-to-day variations in travel time as commuters gain experience with the system. While travel times may be uncertain, these simulations emphasize how people learn about the shape of the congestion profile as opposed to uncertainties resulting from non-recurrent events.

MVA Consultancy and ITS Leeds (1992) report the results of several stated preference studies that analyzed the variability of travel times. They report on 34 studies in their literature search. Most of these were conducted for rail systems. The results confirmed that reliability is an important attribute, but they indicate what seem unreasonably high values; these may result from "protest" responses to hypothetical situations in which travel times exceed those published in train schedules.

More recent studies using stated preference techniques have allowed for more explicit representations of travel-time distributions and the tradeoffs with other attributes. Stated preference means that the survey respondents are asked hypothetical questions, such as how they would choose among two specific scenarios, as opposed to "revealed preference," which measures people's responses to actual situations they are in. Black and Towriss (1993) report on an extensive stated preference study in London to measure the effect of travel-time reliability. They performed in-person interviews and provided respondents with a set of possible travel times to represent travel-time distributions. The results of their estimations show that the standard deviation of travel times is a significant and negative attribute in the travelers' utility function. They perform analyses for different groups of travelers and find that the value of time and variability are highest for those using company cars, followed in decreasing value by train travelers, automobile travelers, and bus travelers. These results do not account separately for scheduling considerations and so cannot distinguish whether the reason for resistance to unreliable travel times is the effects of scheduling cost C_S of Equation 1 or to other costs of unpredictability (e.g., difficulty in planning one's daily activities). The study provides encouraging evidence that survey respondents can understand a stated preference survey that incorporates a distribution of travel times (with an underlying standard deviation).

Small et al. (1995) use a similar survey technique for a sample of commuters in Southern California, adding a departure time attribute. This enables them to analyze scheduling costs and lateness probability separately from other factors. Their results imply that scheduling costs (including the probability of late arrival) explain much of the aversion to uncertain travel times. Once they are controlled for, adding the standard deviation of travel times as an additional independent variable leads to a statistically insignificant coefficient. Unfortunately, Small et al. do not include a travel cost variable in their stated preference questions, so the costs associated with their parameters can only be related to the expected travel-time coefficient.

Abdel-Aty et al. (1994a, 1994b) analyze the effect of travel-time variability on route choice. They performed a stated preference survey in Southern California that presented respondents with pairs of choices between routes. In each pair, one route had an arrival time that was certain, while the other had variability (e.g., one travel time 4 days a week and a longer travel time 1 day a week). In most of the cases presented, the route with variability had a total expected travel time less than the route with certain travel times. The results indicate that travelers recognize the disutility of variable travel times. The number of respondents selecting the more variable route diminished significantly when the standard deviation exceeded about 10 min (for a journey that regularly would take 20 min).

Abdel-Aty et al. (1994a) estimate a binary logit model that shows standard deviation of travel time as having a negative and significant effect on route choice. Abdel-Aty et al. (1994b), using the same data, estimate a Gaussian quadrature model that provides a similar result. There is no cost attribute in their models. The ratio of the coefficients of the standard deviation of travel time to that of expected savings in travel time ranges from 0.33 to 1.0, suggesting that travel-time reliability is important in choosing routes. These results, like those of Black and Towriss (1993), do not attempt to separate scheduling costs from other reasons for aversion to travel-time variability.

Richardson and Cuddon (1994) and MVA Asia (1995) discuss an analysis of a stated preference survey in Melbourne, Australia. A computer-assisted stated preference survey was used to gather information on tradeoffs between cost, travel time, and variability of travel times. Variability was calculated in three different ways—the maximum travel time, the difference between expected travel time and maximum travel time, and the percent difference from expected travel time. The last was considered the most robust measure and had the expected negative sign, but was not statistically significant.

Reliability has been noted to be a major factor in the choice of public transport modes. Benwell and Black (1990), Chang and Stopher (1981), Golob (1970), and Foster (1982) found that almost one-half the users of a bus service in Leeds, England, reported adding at least 10 min to their journey time in order to counteract travel time variability. Bates et al. (1989) mention cases where interviewees report little concern with variability in travel times; perhaps this indicates the greater importance which is attached to scheduling considerations, as suggested by Small et al. (1995).

2.3 VALUING THE RELIABILITY OF FREIGHT TRAVEL

In contrast to passenger travel, research attempting to place a value on the reliability of travel time is not new for freight transportation. The following sections review literature dealing with the theoretical and empirical considerations in measuring reliability in freight transportation. First, some background information on the freight industry dealing with the role of various decision-makers, their decisions, and the tradeoffs involved in their decisions is provided. Then, the sources and measurement of unreliability in freight transportation are discussed.

2.3.1 Decision-Makers, Decisions, and Tradeoffs

The identification of decision-makers, their decisions, and the tradeoffs involved vary with whether one looks at freight transportation alone or logistics operations as a whole. On the one hand, three decision-makers are typically involved in moving a particular shipment of goods from one place to another: the shipper, the receiver, and the carrier. Typically the shipper is the distribution department of a manufacturing firm that supplies goods to the receiver. The receiver is the purchasing department of a manufacturing firm or retailer that purchases goods from the shipper. The carrier is a transportation firm that moves the shipment from the shipper to the receiver. Without losing generality, the following discussion is limited to the case where the carrier is a common transportation firm and the shipper and receiver are each separate firms.

Each of these decision-makers makes decisions regarding the movement of a shipment. First, the shipper selects a mode and carrier.[1] By choosing the carrier, the shipper creates a demand for the carrier's transportation service and pays what the carrier charges for the service. The shipper and carrier are the customer and producer, respectively, in the transportation market. Second, the receiver selects a shipper, decides the shipment size, and chooses its desired schedule for delivery. By choosing the shipper, the receiver creates a demand for the shipper's goods and pays what the shipper charges for the goods. The shipper and receiver are the customer and producer, respectively, in the commodity market. Third, the carrier selects a particular route and schedules the trip from the shipper to the receiver.

These decisions involve tradeoffs among various attributes in freight transportation. These attributes can depend on the mode chosen, the carrier chosen, and the specific route chosen. They may involve differences in transit time and reliability, and these may be affected by different freight charges, the type (or value) of the commodity, potential loss and damages, the shipment size, and a host of other commodity-specific factors. Receivers may also be concerned with inventory levels and scheduling of arrival times.

The story is different if one looks at the logistics operations of a manufacturing firm. The decision-makers typically are the purchasing manager, distribution manager, and inventory manager. These managers make several short-term decisions. The purchasing manager decides the suppliers and the size, number, and schedule of shipments. The distribution manager decides the carrier and mode when the firm does not have its private fleet. The inventory manager decides the levels of inventory stock for both inputs and products. These decisions are often made jointly to minimize the firm's logistics costs, taking into account the value of its inputs and products, freight charges, transit time, and reliability.

Tradeoffs involved in long-term decisions are more complicated than those for short-term decisions. HLB Decision Economics, Inc. (1994) investigates the critical levels of improvements in transit time and reliability at which manufacturing firms are likely to restructure their logistics operations and estimates the savings in logistics costs from the restructuring. Such restructuring would include the adoption of a just-in-time management system and changes in the location, size, and number of plants and warehouses. Quarmby (1989) discusses how the benefits to industry of infrastructure improvement in highways are derived not so much from travel-time savings, but from internal restructuring to take advantage of inventory and locational cost savings.

[1] Most studies assume the shipper chooses the mode and carrier. A few instead assume the receiver chooses the mode and carrier (e.g., Miklius et al., 1976; Winston, 1981; Abdelwahab and Sargious, 1992). As pointed out by Winston (1981), who makes the choice does not matter in the perfectly competitive case because the minimum-cost solution is reached regardless.

2.3.2 Theoretical Contributions

Reliability has been considered in four types of models of demand for freight transportation (Winston, 1983; Zlatoper and Austrian, 1989). These are the modal-split model (Levin, 1978), neoclassical economic model (Oum, 1979), behavioral model (Winston, 1981), and inventory-theoretical model (Baumol and Vinod, 1970). The modal-split and neoclassical economic models are aggregate, while the behavioral and inventory-theoretical models are disaggregate. These models consider reliability in the context of choices for mode, shipment size, or shipment frequency; none of them, however, considers reliability in the context of scheduling decisions. This section summarizes this work; however, the main modeling approach used in this report reflects the theory outlined in the theoretical discussion of passenger travel, in particular the model of Noland and Small (1995).

The modal-split model assumes that the modal split of a particular mode relative to another at the regional or national level is a function of differences between the two modes' attributes. Over small ranges, the function may be approximated as a linear one. This model is not based on any theory of shipper or receiver behavior. It also is restrictive in that a change in the attributes of a third mode cannot affect the modal split of the particular mode in question.

The neoclassical economic model is based on the economic theory of the firm. It derives a mode's share of transportation service at an aggregate level from the cost functions of individual manufacturing firms. These cost functions include the level of output, prices of non-transportation inputs, transportation prices, and shipment characteristics such as transit time and reliability. While this model overcomes the two drawbacks of the modal-split model mentioned above, it is still an aggregate model.

The behavioral model focuses on the decisions made by the physical distribution manager of the receiver or shipper. It is assumed that the manager is concerned with maximizing utility, which depends both on the objective outcome of the choice and on the manager's attitude toward it. One may wonder why the manager does not simply behave in response to profit or cost considerations. The reason, Winston (1981) argues, is that the manager must make decisions under uncertainty and it is the manager's attitude toward risk that requires the use of a utility function. The major drawback of this model is that decisions are modeled in the absence of inventory considerations. This drawback is not serious when the shipper makes these decisions. It could be serious, however, when the receiver makes the decisions because the receiver's purchasing manager is likely to coordinate transportation decisions with those of the receiver's inventory manager.

The inventory-theoretical model considers transportation and inventory decisions jointly for the receiver. It was first developed by Baumol and Vinod (1970). It has been elaborated by others, including Vinson (1972), Constable and Whybark (1978), Allen et al. (1985), Sheffi et al. (1988), Rao and Grenoble (1991), and Tyworth (1992). Various logistics costs can be accounted for in this model, including in-transit inventory cost, stationary inventory cost, freight charges, ordering cost, cost of holding safety stock, and cost of stockout because of unreliability. Several decisions may be considered in this model, including shipment size, shipment frequency, and mode choice. This model has been specified for empirical estimation by McFadden et al. (1985); reliability was not considered in their specifications, however.

2.3.3 Empirical Contributions

Four types of empirical work have contributed to considering reliability in freight transportation: attitude surveys, simulations, revealed-preference analysis, and stated-preference analysis.

2.3.3.1 Attitude Surveys

Attitude surveys attempt to elicit decision-makers' perceptions about the relative importance of various service attributes. Three conclusions may be drawn from attitude surveys. First, reliability seems to be consistently more important than all other attributes for shippers. Second, carriers' perceptions of the importance of reliability to shippers do not differ from the shippers' own perceptions. Third, the importance of reliability varies with groups of shippers.

McGinnis (1989) reviews 11 studies of the relative importance of various factors in shippers' mode or carrier choice. These studies used several different methods for collecting data, including mail-back and personal interviews. Samples varied widely in terms of industry, geography, country, and type of shippers. A set of seven attributes are considered to be important in affecting mode or carrier choice: reliability, transit time, freight rates, loss and damage, shipper market, carrier considerations, and product characteristics. Reliability was identified in all 11 studies. Terms that referred to reliability included dependable transit times, meeting pick-up and delivery dates, on-time performance, or dependability. Although the relative importance of these attributes varies among the studies, reliability seems to be consistently more important than all other attributes (McGinnis, 1989). Deregulation of freight transportation has not changed this ranking, but seems to have reduced the difference in the relative importance of reliability over other attributes (McGinnis, 1990).

Evans and Southard (1974) compare shippers' and carriers' perceptions of the importance of dependability of service in the carrier selection decision. A random sample of shippers and carriers in Oklahoma was drawn. The shippers were asked to rate the importance of 28 factors in their decision of carrier selection. The carriers were asked to rate the same set of factors according to their perception of the importance of these factors to shippers. The mean scores on each factor were computed separately for shippers and carriers, and compared statistically. Reliability was ranked the most important factor by both shippers and carriers. Their mean scores on reliability are statistically the same.

McGinnis et al. (1981) investigate the relative importance of reliability to different groups of shippers—those who use truckload, Less-Than-Truckload (LTL), rail, parcel, and private carriage. The study was based on a national survey of traffic and transportation executives. Logit analysis was carried out to determine what factors are important in explaining this grouping of shippers. The results indicate that truckload, LTL, and private carriage shippers are more likely than other shippers to attach great importance to speed and reliability.

2.3.3.2 Simulations

Simulations attempt to evaluate changes in total logistic costs of a manufacturing firm resulting from improving reliability (Vinson, 1972; Allen et al., 1985; Rao and Grenoble, 1991). For example, Allen et al. (1985) solved a theoretical-inventory model for a cost-minimizing carrier with a range of mean transit times and a range of the variance of transit times. A matrix was prepared that showed the minimum cost attainable with each combination of mean and variance of transit time. Comparing across rows and columns of the matrix allows one to show the change in logistics costs obtainable by changing mean and/or variance of transit time. The authors argue that such a matrix can be used by both the receiver and carrier in negotiating service improvements and freight charges (assuming in this instance that it is the receiver that chooses the carrier). Specifically, the matrix can help the shipper determine how much it is willing to pay for improvements and can help the carrier determine how much it can charge for improvements.

2.3.3.3 Revealed Preference Analysis

Revealed preference analyses attempt to infer the tradeoffs of various service attributes in freight transportation using real-life choices. Several general conclusions may be drawn from revealed-preference studies. First, these studies examine choices of mode or shipment size, but none considers the choice of schedules. Second, the value of reliability improvement can vary significantly across commodity groups. Third, it is difficult to compare the values of reliability improvement from different studies because they all use different ways of measuring freight charges and reliability.

Watson et al. (1974) examined factors that influenced the mode choice between truck and rail of a single shipper of large household appliances. The data came from audit copies of freight bills for individual shipments (over a period which was not reported). These bills included information on (1) origin and destination, (2) date shipped, (3) date received, (4) freight charge, (5) freight rate, and (6) shipment weight. The authors derived from these bills transit time, cost, value of the shipment, and reliability for each mode. How reliability was derived was not reported. The metric of reliability was not stated either—the author's interpretation of the results seems to indicate that reliability was measured by the standard deviation of transit time. The value of shipment and differences in transit time, cost, and reliability entered a logit model linearly. Transit time was marginally significant when only cost and an alternative-specific constant were included; it became insignificant when reliability, value of shipment, or both were added. When included, however, reliability was significant in all four alternative specifications. The model that included cost, transit time, reliability, and value of shipment indicated that the shipper was willing to pay $34.31 per shipment to reduce the standard deviation of transit time by 1 day.

Miklius et al. (1976) used a sample of apple shipments in Washington to estimate a logit model of the receiver's mode choice. The Department of Agricultural Economics, Washington State University, conducted a mail-back survey in 1974 for the 1972 shipping season. The survey obtained information on freight charges, "promised" transit time in number of days, and others, but not on reliability. The following hypothetical question was asked for each mode in a supplementary survey of the receivers: "Suppose that you shipped 100 truckloads of apples. How many of these shipments would arrive on the promised day, one day late, two days late, etc.?" The unit of freight charges was not reported. Reliability was measured by the expected delay in days. The expected delay here is similar to the expected schedule delay late used on the passenger side.

Winston (1981) estimated a probit model of mode choice for each of 13 groups of commodities. The data for agricultural commodities came from a study on produce transportation. The decision-maker was the receiver. The sample contained shipments for the 1975–1976 period. The data for the other groups came from various existing sources containing shipments for the 1976–1977 period. The decision-maker was the shipper. Both data sets included quantity shipped, value of the shipment, freight charges, and mean and standard deviation of transit time. The probit, rather than the more popular logit, model was used because the error terms in the utility functions across modes are not independently distributed, as required by the logit model.

Both the standard deviation and coefficient of variation were included in the models. When the standard deviation was significant but the coefficient of variation was not, the standard deviation had a negative coefficient. When both were significant, however, the coefficient of variation had a positive coefficient. This joint significance occurred for four groups of commodities: unregulated agriculture; regulated agriculture; stone, clay, and glass products; and primary and fabricated metals. The values of reducing the standard deviation of transit time by 1 day, respectively, are $404; $4,110; $3,244; and $1,279 per shipment for the four groups of commodities listed above.

Wilson et al. (1986) examined factors that influence the mode choice decisions of shippers of general freight commodities in the Atlantic provinces of Canada. A mail-back survey was sent to a sample of randomly selected manufacturers in 1984. Respondents were asked to identify the product shipped most frequently, the most regular origin-destination link, and the most regular mode among hired truck, private truck, and rail. The survey obtained information on shipping cost per pound of shipment, transit time in days, in-transit loss and damage in cents per pound of shipment, frequency of shipments, market value per pound of shipment, shipment size in pounds, and reliability. Reliability was defined as the percentage of time that shipments were judged to have arrived at the destination early or on time. Reliability was specified in two alternative forms: (1) probability of not being late and (2) the product of this probability and frequency of shipments.

The logit model was used with independent variables specified linearly. The models were not estimated separately for different groups of commodities. Only those coefficients that the authors considered significant were reported. Neither measure of reliability was significant for hired truck; only the second measure was significant for private truck. Because shipping cost was not significant for any mode, no monetary value of reliability can be derived from this study. However, a value of reliability can be derived in the unit of transit time: shippers are willing to suffer an extra 1.3 days of transit time to reduce late shipments by 1 percentage point.

Ogwude (1990; 1993) estimated a logit model of mode choice by manufacturing firms in Nigeria. The estimation was based on a sample of both outbound and inbound shipments by 244 industrial firms. These shipments included capital goods and four types of consumer goods: food, cloth, chemicals, and durables. Two modes were considered: private carrier and non-private carrier. A survey of these shippers in 1984 obtained information on length of haul, shipment size, freight charges, and transit time. The author derived the standard deviation of transit time from the information on transit time. Results on the marginal rates of substitution between freight charges and reliability are not easily interpreted because their units were not reported. But the author reported a value of 1.6 Naira per ton hour for consumer goods and 0.6 Naira per ton hour for capital goods. From this interpretation, it seems that freight charges were in Naira per ton of shipment and that transit time and standard deviation were in hours. Given these units, the results indicate that these firms were willing to pay for 1.6 and 0.6 Naira per ton of consumer and capital goods, respectively, to reduce the standard deviation of transit time by 1 hour.

Abdelwahab and Sargious (1992) considered the receiver's joint choice of mode and shipment size. Two modes were considered: rail and truck. Different types of commodities were not considered separately; rather, they were partly accounted for by dummy variables, value of shipment, and density of shipment (weight per unit of space). The estimation was based on the 1977 Commodity Transportation Survey (CTS) by the U.S. Bureau of Census. Freight charges, transit time, and reliability of transit time for each mode were derived from this survey using models developed by Roberts and Wang (1979). Reliability was measured by "the number of days above the mean [transit time] on which 95 percent of arrival is achieved." Reliability of the truck mode was specified only in the equation for rail shipment size. The ratio of coefficients between truck reliability and truck freight charges was $323 per pound of shipment per 1-day improvement in reliability.

2.3.3.4 *Stated Preference Analysis*

Stated preference analyses attempt to infer the tradeoffs of service attributes using hypothetical choices. Researchers at the Institute of Transport Studies (ITS), University of Leeds, and MVA Consultancy have been particularly active in this area. Several studies have been undertaken by these institutions using Adaptive Stated Preference, which is discussed in more detail in the next section (Fowkes et al., 1991; Bates and Terzis, 1992). Fowkes et al. (1987) and Fowkes and Tweddle (1988) surveyed freight transport of both bulk and unitized traffic in the United Kingdom and evaluated values of attributes of mode choice. MVA and ITS Leeds (1989) and MVA (1991) considered shipments of unitized goods from the United Kingdom to the Continent and from the Continent to the United Kingdom, respectively.

In addition, Fowkes et al. (1991) investigated the potential for new inter-modal technologies for domestic traffic. Bates and Terzis (1992) investigated the tradeoffs of service attributes in mode choice for shipments of bulk goods for British Rail's Trainload Freight division. ITS Leeds recently undertook a stated-preference survey of traffic managers about how freight is moved with particular reference to choice of mode, quality of service, and route used (Fowkes and Tweddle, 1988).

Stated preference analyses have also been used elsewhere. Richardson and Cuddon (1994) reported on a study of route choice conducted at the Transport Research Centre, Melbourne University, for the proposed Melbourne City Link project. Freight executives of companies were selected through the yellow pages or roadside surveys and contacted. Personal interviews were conducted with the use of computers. The stated preference experiment compared the freeway that was used most recently by the respondent for at least 10 min with a new toll lane to be constructed on the current freeway. The experiments involved four variables: toll, in-vehicle time, reliability of in-vehicle time, and method of payment. Method of payment was presented as either prepayment or cash, and the others were presented with a set of three levels for the two routes, respectively.

Three measures of reliability were tested in the Australia study: maximum journey time, difference between expected and maximum time, and this difference expressed as a percentage of expected time. The last was the preferred measure. For small trucks (not defined), a value of 3.7 cents per 1-percentage point reduction in the difference from expected journey time was derived. For large trucks, the value was insignificant. The authors attributed this difference in the value of reliability to the nature of small and large truck journeys: small trucks make many short journeys, while large trucks make fewer but longer journeys.

2.3.2.5 *Adaptive Stated Preference*

The Leeds Adaptive Stated Preference (LASP) technique is a methodology developed at the Institute for Transport Studies, University of Leeds, to obtain monetary attribute valuations from hypothetical questions presented to small samples. The need for this arose while conducting freight interviews, where the number of potential respondents (firms) in a particular sector might well be less than ten, where only about one-half of these might be willing to be interviewed, or to reveal commercially sensitive information.

Stated preference techniques deal in hypothetical choices, thereby greatly reducing the problem of commercial sensitivity. Furthermore, while an actually observed choice yields just one piece of data, several stated preference questions can be posed to a single respondent, and a given question can obtain several observations about tradeoffs by asking for relative ratings among several options. Given that one can typically ask eight questions of each respondent, it is possible to have enough data to calibrate a rough model for each respondent. By using an ingenious adaptive computerized survey instrument, one can enhance the information content of each piece of information, thereby improving the individual models.

The ingenuity involves making allowance for the different scales used by each respondent. The algorithm has to "learn" the scale used by respondents while quickly locating the option attributes in a suitable area. This allows the algorithm to contend with non-linear response functions, as well as with the greatly different attribute valuations that may occur (e.g., as a result of the traffic being different commodities). Naturally, the algorithm has to be tailored to the particular task at hand, and extensively tested by simulations.

For reasons of commercial sensitivity, one cannot report the individual models, even if they were statistically well fitted. Often they will not be, so similar respondents are combined, taking the attribute-specific monetary valuations as averages of those for individual respondents weighted in accordance with their goodness of fit. In this way, plausible and statistically significant valuations can be derived.

LASP has produced plausible results over a range of commodity types and choice situations. Fowkes et al. (1991) found that, in general, increasing on-time deliveries by 5 percent was valued equivalently to one-half a day's shorter scheduled journey time. Terzis et al. (1992) found reliability to be valued more highly relative to journey time for bulk commodities than for other commodities.

2.3.3.6 Summary of Empirical Studies of Freight

The following points emerge from this review of empirical work on reliability in freight transportation:

1. The most important factors influencing choices in freight transportation include freight charges, value of commodity, loss and damage, transit time, and reliability.
2. The importance of reliability is well established in a variety of choices in freight transportation.
3. Transit time is often measured in days.
4. How reliability is empirically measured is seldom reported in revealed-preference studies.
5. The units of freight charges and reliability vary across theoretical as well as empirical studies. This variation makes any comparison difficult.
6. It is important to estimate values of reliability improvement separately for different groups of commodities.
7. Previous studies have considered reliability for choices of route, mode, and shipment size. They have not considered the carrier's choice of actual schedule or the receiver's desired schedule.
8. Previous studies have not considered the possible costs of shipments being delivered earlier than scheduled.
9. Although it is helpful to use computer-assisted personal interviews for stated preference surveys in freight transportation (such as LASP), postal stated preference surveys have yielded satisfactory results.

2.4 PLANNING PRACTICES

Travel reliability considerations have generally not been incorporated into planning practices. The U. K. Department of Transport is evaluating whether reliability considerations should be included. Reliability has more often been considered important by public transport providers. For example, British Railways use reliability values in their planning process. One result is a relaxation of estimated travel times (as printed in schedules) to increase the percentage of on-time arrivals. This obviously ignores any costs associated with arriving early.

The Highway Economics Requirements System (Jack Faucett Associates, 1991) models the benefits of highway improvements to users but does not account for reliability improvements. Value of travel time is pegged to 60 percent of the wage rate for automobile drivers and 45 percent of the wage rate for automobile and transit passengers. Costs are assumed to be independent of trip lengths. It is common practice to link the value of time to the wage rate (Waters, 1992).

CHAPTER 3

METHODOLOGY FOR PASSENGER SURVEY

In order to provide data for measuring passenger evaluation of congestion and reliability, an extensive survey of passengers in a portion of the greater Los Angeles region was undertaken as part of the current study. This chapter describes the overall strategy and some specific methodological issues, including sampling strategy, survey process, possibility of political biases, questionnaire design, and design of an attribute matrix for the stated preference survey part of the questionnaire.

3.1 SURVEY STRATEGY

The passenger travel survey was conducted in the Route 91 corridor in Orange and Riverside counties in Southern California. New high-occupancy vehicle (HOV) and toll lanes were under construction in the median strip of this freeway at the time of the survey. The researchers purchased a mailing list based on zip codes that parallel Route 91 from Anaheim, Orange, and Placentia in the west to Corona and Riverside in the east. (Appendix A lists the zip codes used.) Route 91 is the only major road passing through the Santa Ana Mountains. This geographical constraint places most residents in this area within 2 miles of the highway and results in many residents having a limited choice of routes.

Considerable effort was spent developing a survey instrument that was easy for the respondents to understand and answer. Each person chosen as a survey subject first received a "transportation survey" that asked basic questions about their travel and themselves, with special attention to their scheduling constraints and choices. Those who responded then received a "customized transportation survey," referred to here as the "stated preference survey." As noted earlier, stated preference means asking people how they would respond to hypothetical situations. In this case, they were given two rather complete descriptions of a possible commuting experience and asked to choose which they would prefer.

The researchers attempted to maximize the response rate by following procedures outlined in Dillman (1978), specifically:

1. Postcard follow-up 1 week after initial survey mailing.
2. Follow-up with another survey 3 weeks after initial mailing.
3. Personalized cover letters for each respondent, including signature in blue ink.
4. Careful attention to question wording and cover letters, including capitalizing the possible answers to the question.
5. Cash incentive in the form of a lottery for $400 for all respondents who return both surveys.

One problem that has occurred with previous research in this area is that people answer questions with a political bias. In particular, a pilot test conducted for Small et al. (1995) found that people always selected the lowest cost option when the word "toll" was explicitly used. For this reason, the researchers avoided the use of the word "toll," which is politically controversial. Instead, it was stated that there are certain costs "that may be assumed to include vehicle operating costs, gasoline, parking, and any other miscellaneous costs associated with the trip."

The research team conducted two preliminary tests of the stated preference questions to determine whether the wording of the questions were resulting in answers that reflected political biases. The first test used an undergraduate economics class at UC Irvine (see Appendix D). Certain stated preference questions in this test were designed to encourage most people to select the higher cost choice (e.g., in one question, a small cost difference would result in 15 min less average travel time). Answers to these questions were cross-tabulated with answers to two other questions, one asking about concern for the environment and the other asking explicitly about opposition to toll roads. There were no statistical differences among these categories (using a chi-square test) in the percentage choosing the lower cost option. In fact, for all of these questions, most respondents chose the higher cost option, indicating that they are willing to pay a cost for travel time advantages, regardless of political beliefs about environmentalism and toll roads. Other questions, designed to provide more borderline tradeoffs between travel time and costs, resulted in plausible splits (in the 40 to 60 percent range) and again no statistically significant differences in results between respondents grouped by their answers to the political questions. These results gave the research team confidence that the wording of the questions has eliminated any major political biases in responses.

The second preliminary test was a full-scale pilot study using the purchased mailing list. This test revealed no problems and resulted in virtually no change in the questionnaire, so these respondents are included in the total sample for analysis.

3.2 DESIGN OF STATED PREFERENCE QUESTIONS

The stated preference survey contained two distinct experiments. One focused on the tradeoff among travel time, travel-time variability, departure time, and cost. The other focused on the tradeoffs among free-flow travel time, congested travel time, and cost. The question formats are shown below as Experiment #1 and Experiment #2, respectively.

EXPERIMENT #1 (SAMPLE QUESTION)

PLEASE CIRCLE EITHER CHOICE **A** OR CHOICE **B**

Average Travel Time: **9 minutes**	Average Travel Time: **9 minutes**
You have an equal chance of arriving at any of the following times:	You have an equal chance of arriving at any of the following times:
7 minutes early	**3 minutes early**
4 minutes early	**3 minutes early**
1 minute early	**2 minutes early**
5 minutes late	**2 minutes early**
9 minutes late	**On time**
your cost: **$0.25**	your cost: **$1.50**
Choice A	**Choice B**

EXPERIMENT #2 (SAMPLE QUESTION)

PLEASE CIRCLE EITHER CHOICE **A** OR CHOICE **B**

Average Total Travel Time: **11 minutes**	Average Total Travel Time: **8 minutes**
Percent of total time spent in stop and go traffic: **36%**	Percent of total time spent in stop and go traffic: **38%**
your cost: **$0.25**	your cost: **$1.50**
Choice A	**Choice B**

The questions involving travel-time variability follow the general format pioneered by Black and Towriss (1993) and make use of both their experience and that of Small et al. (1995). Black and Towriss experimented with several formats and found that people could interpret a five-point distribution of travel times reasonably well. The research team adopted that basic format, but added both a cost and a departure time. However, unlike Small et al. (1995), the researcher team made the departure time implicit by listing not the five individual travel times but rather the average travel time and the five individual arrival times, expressed as minutes early or late. This choice was based on analysis of the preliminary test, in which the researcher team believed people did not correctly calculate either the average travel time or the precise distribution of early or late arrivals just from the raw information. Even with these simplifications, there is a danger that too much information is presented and the respondent may, therefore, ignore some of it; one of the findings can be interpreted as resulting from this problem and is discussed in the section on analysis.

For Experiment #2, the research team decided to present the percent of total time spent in congested traffic rather than the absolute amount of time. In preliminary tests, the researchers presented respondents with both total travel time and travel time spent in congestion, but it seemed that respondents may have been adding the two travel times together. The wording the research team used to describe congestion is "stop and go traffic," which the researchers interpret to mean Level of Service E or F.

3.3 STATED PREFERENCE SURVEY ATTRIBUTE DESIGN

The specific attribute levels for each stated preference design were developed by the MVA Consultancy. This process consisted of analyzing various attribute levels and performing simulations on hypothetical data sets to determine whether the range of the attributes is adequate for estimation purposes.

For a given actual travel-time interval (determined from the transportation survey), a set of three possible levels was determined for each attribute (cost, average travel time, and standard deviation of travel time). The research team attempted to specify values that would seem realistic to that respondent. For cost, the lowest of the three values was based on assumptions about average travel speeds and vehicle operating costs; the other two values were higher. The research team specified whether respondents should consider the questions as pertaining to a work trip or a non-work trip (the former possible only if they indicated in the transportation survey that they drive to work regularly). In addition, the researchers presented Experiments #1 and #2 in reverse order to half the respondents. In all, this customization resulted in 72 different versions of the stated preference survey. See Appendix C for a full account of the survey design.

The version of the survey received by a given person was based on that person's answers in the prior transportation survey. In cases where several of the 72 versions would have been equally appropriate, an attempt was made to distribute the versions so as to receive a similar number of responses for each version.

3.4 SURVEY PROCESS

In mid-1995, 2,500 surveys were sent to residents along the SR 91 corridor. Addresses were obtained from a commercial firm and limited to certain zip codes adjacent to the corridor. The first 200 were a pilot test mailed on July 7, while the other 2,300 were the main survey mailed on November 15. In the case of the main survey, extensive follow-up was undertaken. Reminder postcards were sent out after 1 week and again after 2 weeks; if no response was received by the end of the 3rd week, a duplicate survey instrument was sent, again followed by weekly reminder postcards.

When the first completed survey instrument (the transportation survey) was received at the project office, the customized stated preference survey questionnaire was mailed within 1 day. This was followed by the same follow-up procedure of reminder cards and, if necessary, a duplicate questionnaire.

The research team ultimately received 1,348 completed and usable transportation surveys, and 959 completed and usable stated preference surveys. (About 6 percent of the non-responses were bad addresses or were rejected on the basis of other miscellaneous factors.) These figures represent response rates of 53.9 percent and 71.1 percent on the two survey parts. The combined rate, that is the proportion of the original mailing that resulted in both instruments being completed, was 38.4 percent. These excellent rates are a result of the careful design of the questionnaire, particularly the research team's resolve to keep it brief and simple, and the detailed follow-up strategy.

CHAPTER 4

DESCRIPTIVE RESULTS OF PASSENGER TRANSPORTATION SURVEY

4.1 SURVEY POPULATION AND RESPONSE RATES

Of the 2,500 surveys mailed, there were 1,348 responses for a response rate of 53.9 percent.

4.2 SURVEY FINDINGS

This section reports frequency distributions from the 1,348 responses to the transportation survey, the first of the two-part mail survey. For some questions, approximate median responses are shown; these are computed from the intervals shown by interpolating between the percentile points defining the beginning and end of the interval that contains the 50th percentile.

Of those returning the survey, 63.9 percent are male. The most common residential locations are in the cities of Anaheim, Riverside, and Orange, with smaller numbers from other cities near State Route 91 (in Riverside and Orange counties).

Table 1 gives respondents' employment status. Over 60 percent are employed outside of the home or are students.[1] Of these, the most common cities where work or school are located are Riverside (11 percent), Anaheim (8 percent), Orange (5 percent), Santa Ana (3 percent), Irvine (3 percent), and Corona (3 percent). Of those employed outside the home, 7.2/(50.5 + 7.2) = 12.2 percent work part-time.

The research team obtained income information from the respondents in two ways. First, the team asked respondents for their average weekly *personal* income, reported in Table 2. Then the team asked for respondents' annual gross *household* income before taxes, reported in Table 3. The annual gross household income is less than $15,000 in 5.5 percent of the households and more than $125,000 in 7.1 percent of the households; median income is approximately $55,000.

The median personal weekly income is approximately $750. This is useful for estimating the wage rate. The research team asked those respondents, who were currently employed, how many hours per week they work. The median response was 39 hours. This exactly matches the U.S. as a whole for 1994 (U.S. Bureau of the Census, 1995, Table 645). Median hourly earnings are therefore approximately $19.20.

With these demographic statistics in mind, one can now consider the following transportation-related data. For those working or attending school, Tables 4 and 5 show the distributions of distance and time, respectively, of their trip to work or school. With median distance of about 15 mi and median time of about 26 min, these trips are typical of work trips throughout the Los Angeles area and indeed throughout the nation. Although nearly 20 percent of the respondents commute 5 mi or less, some respondents who live in the area commute very long distances: 5 percent of the respondents commute more than 50 mi one way to work or school.

Tables 6 and 7 provide information about the timing of trips to work or school. The most popular times of departure are between 6:30 am and 8:30 am, accounting for just over one-half the sample; these hours represent the general morning peak hours for Los Angeles area commuters. Another 18.7 percent depart between 5:00 am and 6:30 am. Only a few depart from home in the afternoon or at night. This seems to indicate only a very limited number of shift and/or part-time employees among the respondents, consistent with Table 1. The differences between Tables 6 and 7 suggest that a substantial number of the early departures are very long trips, most likely to destinations in Los Angeles county. These trips either suffer very severe congestion or are timed very early in order to avoid it.

Table 8 shows how respondents view the tolerance at their workplace for late arrival. Approximately 30 percent state that they can arrive at any time with no penalty to their job status or take-home pay, while another 12 percent have flexibility of 20 min or more. At the opposite extreme, 32.5 percent have jobs with less than 5 min lateness tolerance. The median time a person can be late is between 10 and 14 min.

Nearly all those traveling to work or school do so by automobile, as shown in Table 9. Most (83 percent) drive alone, while about 13 percent carpool. About 4 percent of the people use other ways to get to work or school including walking, riding a bicycle, and taking public transportation.

Of the 13 percent who use carpool as their "generally used mode," only two-thirds do so every workday. On the other hand, there is nearly another 15 percent who do not consider carpool their usual mode but who use it sometimes. Table 10 shows the full frequency distribution of carpooling. Table 11 shows the number of other people in the cars with the carpoolers; as expected, most carpoolers (72.9 percent) travel

[1] Note that the totals in Table 1 and the following tables may not add to 100 percent because of rounding.

TABLE 1 Employment status

STATUS	PERCENT
Employed full-time	50.5
Employed part-time	7.2
Full-time students	1.7
Part-time students	1.6
Unemployed	1.6
Homemaker	5.4
Self-employed	10.8
Retired	19.5
None of the above	0.4
	100

TABLE 2 If employed, average weekly personal income

WEEKLY INCOME	PERCENT
Less than $200	7.5
$201–$400	12.3
$401–$600	17.3
$601–$800	17.3
$801–$1000	17.0
$1001–$1200	7.6
$1201–$1400	5.6
$1401–$1600	6.0
$1601–$1800	1.6
$1801–$2000	4.0
More than $2000	3.9
	100

Median: approximately $750/week
Median hourly earnings (see text): approximately $19.20

TABLE 3 Total gross household income before taxes

HOUSEHOLD INCOME	PERCENT
Less than $15000	5.5
$15000–$24999	9.5
$25000–$34999	11.0
$35000–$44999	12.3
$45000–$54999	11.9
$55000–$64999	9.5
$65000–$74999	8.9
$75000–$99999	15.6
$100000–$124999	8.7
More than $125000	7.1
	100

Median: approximately $55,000/year

with just one other person (HOV-2), while the rest are split evenly between HOV-3 and HOV-4+.

The above questions were designed to study the general commuting habits of people living in the areas around Freeway 91. However, the research team also asked the survey participants to answer questions about their commuting experiences directly on Freeway 91—the most typical east-

TABLE 4 Miles normally traveled to work or school, one way

MILES	PERCENT
5 miles or less	18.8
6–10 miles	17.8
11–15 miles	14.7
16–20 miles	10.0
21–25 miles	9.2
26–30 miles	7.4
31–35 miles	6.8
36–40 miles	4.5
41–45 miles	3.1
46–50 miles	2.5
51–55 miles	1.0
56–60 miles	1.0
61–65 miles	1.2
66–70 miles	.2
More than 70 miles	1.9
	100

Median: approximately 15 miles.

TABLE 5 Normal travel time, door to door, one-way, to work or school

MINUTES	PERCENT
10 minutes or less	13.5
11-20 minutes	24.4
21-30 minutes	19.0
31-40 minutes	13.7
41-50 minutes	10.4
51-60 minutes	6.9
61-75 minutes	5.9
76-90 minutes	4.1
More than 90 minutes	2.0
	100

Median: approximately 26 minutes.

west route through the area, which is generally highly congested and which was the location of median improvements during the course of the survey. The following paragraphs and tables summarize respondents' answers.

Table 12 shows that more than one-half of the respondents use Route 91 2 days or more a week. Furthermore, about 35 percent of the people use Route 91 regularly (i.e., at least 5 days week). Only about 8 percent of the respondents never use Route 91.

The research team next asked about "the most frequent type of trip that you make on Route 91." Thirty-five percent answered that the most frequent type of trip is to or from work or school. The next frequent type of trip is shopping or personal business. The 35 percent commuters corresponds to the previous question about the number of people who use the roadway regularly.

The team then asked the destination of their last non-commuting trip taken on Route 91. The cities most often mentioned were Riverside (9 percent), Anaheim (9 percent), and Corona (7 percent).

TABLE 6 Normal departure time from home for work or school

DEPARTURE TIME	PERCENT
Midnight–4:59 am	7.2
5:00 am–5:29 am	4.9
5:30 am–5:59 am	6.0
6:00 am–6:29 am	7.8
6:30 am–6:59 am	11.5
7:00 am–7:29 am	17.2
7:30 am–7:59 am	13.6
8:00 am–8:29 am	10.4
8:30 am–8:59 am	6.2
9:00 am–9:29 am	5.0
9:30 am–9:59 am	1.2
10:00 am–10:59 am	1.0
11:00 am–11:59 am	1.1
12:00 pm–12:59 pm	0.1
1:00 pm–1:59 pm	1.0
2:00 pm–2:59 pm	1.3
3:00 pm–3:59 pm	0.5
4:00 pm–4:29 pm	0.4
4:30 pm–4:59 pm	0.2
5:00 pm–5:29 pm	0.3
5:30 pm–5:59 pm	0.4
6:00 pm–6:29 pm	0.2
6:30 pm–6:59 pm	0.2
7:00 pm–midnight	2.1
	100

TABLE 7 Normally desired work arrival time

DESIRED WORK ARRIVAL TIME	PERCENT
Midnight–4:59 am	2.5
5:00 am–5:29 am	1.6
5:30 am–5:59 am	5.2
6:00 am–6:29 am	6.3
6:30 am–6:59 am	9.0
7:00 am–7:29 am	13.1
7:30 am–7:59 am	15.9
8:00 am–8:29 am	16.2
8:30 am–8:59 am	9.5
9:00 am–9:29 am	7.6
9:30 am–9:59 am	2.4
10:00 am–10:59 am	2.5
11:00 am–11:59 am	0.9
12:00 pm–12:59 pm	0.1
1:00 pm–1:59 pm	0.8
2:00 pm–2:59 pm	1.0
3:00 pm–3:59 pm	1.1
4:00 pm–4:29 pm	0.1
5:00 pm–5:29 pm	0.5
5:30 pm–5:59 pm	0.3
6:00 pm–6:29 pm	0.2
6:30 pm–6:59 pm	0.5
7:00 pm–midnight	2.5
	100

TABLE 8 Lateness tolerance without impact on job status or pay

TOLERANCE	PERCENT
5 minutes or less	32.5
5-9 minutes	10.1
10-14 minutes	9.3
15-19 minutes	6.2
20 minutes or more	12.2
Can arrive at any time	29.7
	100

TABLE 9 Mode generally used for travel to and from work or school

MODE OF TRANSPORTATION	PERCENT
Drive car alone	83.0
Carpool with family members	6.7
Carpool with non-family	6.2
Take bus	0.6
Other	3.4
	100

TABLE 10 If they carpool, how many days a week they carpool

FREQUENCY OF CARPOOLING	PERCENT
5 days per week or more	10.3
2-4 days per week	7.8
One day per week	3.3
Less than 1 day per week	7.6
Never use a carpool	70.9
	100

TABLE 11 If they carpool, how many other people they carpool with

NUMBER OF PEOPLE	PERCENT
One Other Person	72.9
Two Other People	13.8
Three or More	13.4
	100

TABLE 12 Frequency of use of Route 91

FREQUENCY OF USE OF SR-91	PERCENT
5 days a week or more	35.2
2–4 days a week	26.3
One day a week or less	30.4
Never use Route 91	8.1
	100

Table 13 shows the time when respondents started their last non-commuting trip on Route 91. The median starting time for non-work trips was between 11:00 am and 12:00 noon, around lunch time. Less than 10 percent of the people got an early start, beginning their trip between midnight and 8:00 am. (About half of those started between 7:00 am and 8:00 am). About 10 percent of the surveyed people took a late trip, starting between 7:00 pm and midnight.

TABLE 13 Departure time from home of most recent non-commuting trip taken on Route 91

DEPARTURE TIME	PERCENT
Midnight–4:59 am	0.7
5:00 am–5:29 am	0.6
5:30 am–5:59 am	0.6
6:00 am–6:29 am	1.7
6:30 am–6:59 am	0.7
7:00 am–7:29 am	2.9
7:30 am–7:59 am	1.2
8:00 am–8:29 am	5.7
8:30 am–8:59 am	2.2
9:00 am–9:29 am	10.6
9:30 am–9:59 am	3.6
10:00 am–10:59 am	17.4
11:00 am–11:59 am	11.4
12:00 am–12:59 pm	0.4
1:00 pm–1:59 pm	6.8
2:00 pm–2:59 pm	4.7
3:00 pm–3:59 pm	5.3
4:00 pm–4:29 pm	3.4
4:30 pm–4:59 pm	0.8
5:00 pm–5:29 pm	2.7
5:30 pm–5:59 pm	0.9
6:00 pm–6:29 pm	3.4
6:30 pm–6:59 pm	1.7
7:00 pm-12 am	10.6
	100

The research team next asked the one-way distance and door-to-door travel time of the most recent non-commuting trip on Route 91. These results are shown in Tables 14 and 15. The median trip was about 28 mi and took about 35 min, reflecting the role of Route 91 as a major inter-city arterial.

Table 16 shows the day the most recent non-commuting trip was taken that uses Route 91. Just over 43 percent were taken on the weekend, most commonly on Saturday.

The number of people in the car on the most recent non-commuting trip on Route 91 is shown in Table 17. Unlike trips to work or school, trips to other destinations and that use Route 91 are mostly taken in the company of one or more passengers. Approximately 70 percent of the surveyed people were accompanied by one or more people.

TABLE 14 Length, in miles, of most recent non-commuting trip on Route 91 from home

MILES	PERCENT
5 miles or less	5.4
6–10 miles	12.8
11–15 miles	9.9
16–20 miles	10.5
21–25 miles	7.3
26–30 miles	9.1
31–35 miles	4.3
36–40 miles	7.3
41–45 miles	3.3
46–50 miles	5.4
51–55 miles	0.8
56–60 miles	4.7
61–65 miles	1.3
66–70 miles	2.5
71–80 miles	2.7
81–90 miles	2.1
91–100 miles	2.8
101–110 miles	0.8
111–120 miles	2.0
121–210 miles	2.5
211–300 miles	0.9
More than 300 miles	1.8
	100

TABLE 15 Door-to-door travel time of most recent non-commuting trip on Route 91

MINUTES	PERCENT
10 minutes or less	4.5
11–20 minutes	15.1
21–30 minutes	15.6
31–40 minutes	11.6
41–50 minutes	11.1
51–60 minutes	7.6
61–75 minutes	5.7
76–90 minutes	2.7
More than 90 minutes	6.2
	100

TABLE 16 Day of the week of the most recent non-commuting trip on Route 91

DAY OF TRIP	PERCENT
Monday	8.6
Tuesday	10.2
Wednesday	12.9
Thursday	11.1
Friday	13.6
Saturday	28.5
Sunday	15.0
	100

TABLE 17 Number of people in the car on the most recent non-commuting trip on Route 91

NUMBER OF PEOPLE IN THE CAR	PERCENT
Driver only	32.6
Drive plus 1 passenger	39.7
Driver plus 2 or more passengers	27.7
	100

CHAPTER 5

ANALYSIS OF PASSENGER SURVEY RESULTS

5.1 EFFECT OF CONGESTION ON VALUE OF TIME

The portion of the stated preference survey referred to as Experiment #2 asks people to choose among situations in which they have to trade off total travel time, the fraction of travel time in congested conditions, and trip cost. Using standard modeling techniques, these data can be used to estimate how these people view the tradeoffs.

The research team's basic model is based on a choice index (sometimes called systematic utility) that is linear in the three variables presented as traits of the choices. This can be written as follows:

$$V = \beta_T T + \beta_{fc}(T_c/T) + \beta_M M \tag{3}$$

where T is total travel time, T_c is time spent in congested conditions, and M is monetary cost. If the parameters denoted by β are known, the value of V can be computed for each of the two alternatives, A and B, from which the respondent was asked to select. Call these values V_A and V_B. Following standard methods in travel demand analysis, one assumes that alternative A is chosen over alternative B with increasing probability as $V_A - V_B$ rises. Probit and logit analysis are obvious models to quantify this relationship; the research team used logit for analytical convenience, giving the probability of choosing alternative A as follows:

$$\text{Prob(choice A)} = \frac{1}{1+\exp(V_B - V_A)} \tag{4}$$

where exp denotes the exponential function.

The logit estimation routine finds values for the β coefficients that make these probabilities match as closely as possible the actual choices observed in the sample, in the sense of maximizing the likelihood value of the entire sample.

In the sample, each individual was asked to choose among several pairs of alternatives (six pairs if all the questions were answered). These were treated as separate observations, although econometrically this will tend to overstate somewhat the precision and statistical significance of the coefficient estimates because the choices for a given individual are not likely to be truly independent of one another. Thus the t-statistics shown in the tables should be regarded as upper bounds; a lower bound would be obtained by dividing them by $\sqrt{6} = 2.45$ (Louviere and Woodworth, 1983). Thus, a coefficient with an uncorrected t-statistic of 2.0 is regarded as being potentially statistically significant, whereas only if the t-statistic is as high as 4.9 does it unambiguously meet standard criteria for significance (at the 5 percent level).

Model 1 of Table 18 shows the logit estimate for Equation 3. Travel time is in minutes, cost is in dollars, and the fraction of travel time that is congested (the variable *fc*) is given as a fraction.

The implied value of total travel time is the ratio of the coefficient of "total travel time" to that of "monetary cost," which comes to \$0.1055 per minute or \$6.33 per hour. This value is shown in the middle column of Table 19. Recall from Table 2 that median hourly earnings for this sample are approximately \$19.20. Thus the value of total travel time is estimated at 33 percent of the wage rate—well within the range expected from the literature reviewed in Chapter 2. However, this value is toward the lower end of that range, whereas one might have expected it to be toward the higher end because travel time in these experiments includes a substantial fraction of congestion, which is quite severe in the ordinary experience of many of the sample respondents. This may be because the question and, indeed, the entire survey, focuses attention on congestion rather than on total travel time. Survey respondents, therefore, probably gave somewhat more weight to congested relative to uncongested travel time than they might in actual situations.

The coefficient of fraction of time spent in congestion is large and estimated with high precision. The estimate implies that for a trip with a given total travel time, adding 10 percent to the portion that is congested is just as onerous as adding \$0.76 to the trip cost (because $0.10 \times 7.3622/.9655 = 0.76$).

Another way to look at these results is to ask: What is the perceived cost to the user of shifting 1 min of travel time from being uncongested to being congested? The easiest way to answer this is to rewrite the "utility" of Equation 3 in terms of monetary cost and perceived travel cost as follows:

$$V = \beta_M \cdot (C_t + M) \tag{5}$$

where

$$C_t \equiv (\beta_T/\beta_M)T + (\beta_{fc}/\beta_M)(T_c/T). \tag{6}$$

TABLE 18 Model development of second experiment data

Explanatory variables	Model 1	Model 2	Model 3	Model 4	Model 5
Total travel time	–.1018	–.1142	.09541	–.11331	–.09286
T	(–9.317)	(–9.248)	(–7.842)	(–5.363)	(–7.931)
Non-working person * T	—	.01885	.009713	–.005769	—
NW*T		(1.332)	(0.689)	(–0.369)	
Low income * T	—	.03873	—	—	—
LOI*T		(3.069)			
(Income-65)*T	—	—	–.0009874	–.001002	–.001044
YM*T			(–6.417)	(–6.098)	(–7.051)
Female*T	—	—	—	.01373	—
F*T				(1.091)	
Adults*T	—	—	—	.001741	—
AD*T				(0.244)	
Age*T	—	—	—	.02204	—
AGE*T				(1.672)	
Fraction congested travel	–7.3622	–7.3626	–7.1334	–7.3118	–7.2716
fc	(–23.111)	(–19.326)	(–19.967)	(–10.393)	(–21.559)
Non-working person * fc	—	–.6152	–.6454	–1.0723	—
NW*fc		(–1.300)	(–1.371)	(–2.069)	
Lower income * fc	—	.6296	—	—	—
LOI*fc		(1.491)			
(Income-65)*fc	—	—	–.009412	–.008223	—
YM*fc			(–1.678)	(–1.406)	
Female*fc	—	—	—	.2907	—
F*fc				(0.696)	
Adults*fc	—	—	—	–.1441	—
AD*fc				(–0.637)	
Age*fc	—	—	—	.7563	—
AGE*fc				(1.662)	
Monetary cost	–.9655	–.9274	–.9267	–.9252	–.9257
M	(–20.016)	(–18.288)	(–18.180)	(–17.766)	(–18.168)
Sample size	5644	5056	5056	4918	5056
Log likelihood	–3455.223	–3099.111	–3081.217	–2992.436	–3083.235
Log likelihood on N = 5056	–3108.633	–3099.111	–3081.217	NA	–3083.235
Log likelihood on N = 4918	—	—	–2996.505	–2992.436	—
p-value for lik. ratio test of current model vs.:					
Model 1	—	.0008	.0000	—	.0000
Model 3	—	—	—	.2282	—

Note: t-statistics (shown in parentheses) are uncorrected for dependence among observations from the same respondent (see text).

TABLE 19 Implied values of total travel time

Household annual income ($1,000s)	Value of total travel time ($/hour)	
	Model 1	Model 5
15	6.33	2.64
35	6.33	3.99
55	6.33	5.34
75	6.33	6.70
95	6.33	8.05

The quantity C_t represents the perceived time cost for the trip, including an allowance for the inconvenience or "uncomfortableness" of having some of that time be under congested conditions. If 1 min of travel time is shifted from being uncongested to being congested, the first term on the right-hand side of Equation 6 is unchanged, but the second term increases by $\Delta C_t = (1/T)(\beta_{fc}/\beta_M) = \$7.625/T$. A few values of this cost increment are shown in Table 20.

For the median trip length of 26 min, such a shift is worth $0.29, or nearly three times the value of the time itself. This is a much larger differential between total travel time and congested travel time than has been found in previous stud-

TABLE 20 Perceived cost increment from shifting one minute from uncongested to congested travel

Total travel time (min.)	Cost increment ($ per minute)	
	Model 1	Model 5
10	0.76	0.79
15	0.51	0.52
26	0.29	0.30
30	0.25	0.26
45	0.17	0.17
60	0.13	0.13

ies and may partly reflect the respondents' focusing on congestion because of their understanding that it was a major point of the survey.

Models 2 through 4 in Table 18 explore how these valuations of total time and congested time vary with employment status, household income, sex, family size, and age. Surprisingly, income is the only such variable that has much effect, and its effect is mainly on the valuation of total travel time rather than on that of congested travel time. Comparing Models 2 and 3, one sees that income performs better as a continuous variable than as a simple dummy for those with incomes below $45,000 per year. For convenience, the variable is defined as $YM * Y - 65$ where Y is household income (unit in thousand dollars); this makes it easier to compare models because the variables that involve multiplication by YM are zero at a household income of $65,000. Of course, Y is not strictly continuous, but rather consists of midpoints of the intervals listed in Table 3.

Other interactions were tried, including carpooling, carpooling with a family member, carpooling to work, and carpooling to work in families with children. None was statistically significant.

The last model in the table, Model 5, retains only the interaction between income and total travel time from all the socioeconomic interactions tried in the previous three models. This model is probably the best overall summary of the results. Its implications are similar to those of Model 1 except that the value of time now depends on income. Specifically, the ratio (β_T/β_M) in first term on the right-hand side of Equation 6 is replaced by the following:

$$\text{value of total travel time} = \frac{\beta_T + \beta_{YM} \cdot (Y - 65)}{\beta_M} \qquad (7)$$

These implied values of time are shown in the last column of Table 19. These results show the value of time rising with income but less than proportionally, consistent with the findings of MVA Consultancy et al. (1987).

The relative values of congested versus uncongested time are shown in the last column of Table 20; they are calculated as before, except using the slightly different coefficient estimates which in this case imply that $\Delta C_t = \$7.855/T$.

Table 21 provides a different specification, in which congested travel time appears as an absolute amount (in minutes) instead of as a fraction. In Model 6 the value of uncongested travel time is constant at (β_T/β_M) = $0.0035 per minute or $0.21 per hour, while the differential value of congested relative to uncongested travel time is also constant, at (β_{fc}/β_M) = $0.204 per minute or $12.23 per hour. As with the fractional specification, income affects the value of total travel time but not the differential between uncongested and congested travel time. This observation leads to Model 10 as the preferred model of the set shown in Table 21.

Although the first three models in Table 21 fit somewhat better than the corresponding models in Table 18 (by the criterion of likelihood value achieved), they are less satisfactory as a description of behavior because they show uncongested travel time to be valued essentially at zero. This is probably because of the survey's focus on congestion, as discussed earlier. When the research team explicitly isolated uncongested travel time, whose value was not presented directly to the respondents, the researchers were perhaps pushing the limits of the methodology unreasonably. Therefore, the research team has greater confidence in the models of Table 18, which use the variables total travel time and fraction congested, just as they were presented to people in the survey. Also, the preferred Model 5 of Table 18 fits better than its counterpart in Table 21.

5.1.1 Recommendations for Practice

Prior research provides plenty of evidence on the value of total travel time, and the results are consistent with it. Therefore, the research team sees no reason to alter current practice in valuing total travel time.

The results on the differential value of congested relative to uncongested travel time are summarized by the equation $\Delta C_t = \$7.855/T$ that gives the values shown in the last column of Table 20, where T is door-to-door total trip time. This equation gives the additional cost, as perceived by the user, of spending a minute in traffic at Level of Service E or F instead of in traffic at Levels of Service A through D. (This is regardless of whether or not the congestion is recurrent, because the effects of uncertainty are taken into account separately—see Section 5.2.). These values provide a reasonable basis for modifying current practice to account for congested conditions. These values are derived from a survey that highlighted congestion, and people answering the survey are exposed to very high levels of congestion; therefore, these values are probably toward the upper end of the range likely to apply in various metropolitan areas in the United States. This observation is consistent with the small amount of prior research on the value of congested travel time, as reviewed earlier.

TABLE 21 Model development of second experiment data

Explanatory variables	Model 6	Model 7	Model 8	Model 9	Model 10
Total travel time	.003154	–.01349	.005790	–.03392	.01165
T	(0.366)	(–1.290)	(0.577)	(–1.526)	(1.257)
Non-working person * T	—	.03261	.02483	.008480	—
NW*T		(1.960)	(1.499)	(0.472)	
Low income * T	—	.04006	—	—	—
LOI*T		(2.726)			
(Income-65)*T	—	—	–.0009504	–.000997	–.0009998
YM*T			(–5.267)	(–5.170)	(–6.727)
Female*T	—	—	—	.02550	—
F*T				(1.733)	
Adults*T	—	—	—	.009779	—
AD*T				(1.174)	
Age*T	—	—	—	.02538	—
AGE*T				(1.931)	
Congested travel time	–.1825	–.1729	–.1712	–.1350	–.17772
ctt	(-22.972)	(–18.554)	(–19.411)	(–7.776)	(–21.139)
Non-working * ctt	—	–.0266	–.02741	–.02988	—
NW*ctt		(–1.969)	(–2.044)	(–2.172)	
Low income * ctt	—	.04006	—	—	—
LOI*ctt		(2.726)			
(Income-65)*tt	—	—	–.0000496	.0000253	—
YM*ctt			(–0.337)	(0.162)	
Female*ctt	—	—	—	–.01317	—
F*ctt				(–1.130)	
Adults*ctt	—	—	—	–.01461	—
AD*ctt				(-2.183)	
Monetary cost	–.8956	–.8498	–.8446	–.8383	–.8434
M	(–19.726)	(–17.784)	(–17.601)	(–17.152)	(–17.587)
Sample size	5644	5056	5056	4918	5056
Log likelihood	–3445.469	–3096.877	–3081.280	–2992.095	–3083.590
Log likelihood on N = 5056	–3106.629	–3096.877	–3081.280	NA	–3083.590
Log likelihood on N = 4918	—	—	–2997.816	–2992.095	—
p-value for lik. ratio test of current model vs.:					
Model 6	—	.0006	.0000	—	.0000
Model 8	—	—	—	.0433	—

Note: t-statistics (shown in parentheses) are uncorrected for dependence among observations from the same respondent (see text).

5.2 EFFECT OF TRAVEL-TIME UNCERTAINTY ON TRAVEL BEHAVIOR

Responses to the stated preference questions involving reliability provide a rich data base for assessing how people are affected by the travel-time uncertainty of their trips. In particular, the responses indicate how people's scheduling preferences and constraints color their responses to travel-time uncertainty. This is because the research team specified trip schedules in the alternative scenarios presented to the survey respondents. One can estimate the implicit costs that people incur because of travel-time uncertainty and ascertain the components of these costs and how they are related to scheduling costs under that uncertainty.

In this report, the unit cost of travel-time uncertainty is referred to interchangeably as "value of reliability," "cost of unreliability," or "cost of uncertainty." It is the monetary equivalent of a marginal change in some measure of travel-time uncertainty, normally the standard deviation. More formally, it is the marginal rate of substitution between a trip's travel-time uncertainty and its cost, for a particular type of traveler or type of trip as distinguished in the variables of the model.

As a starting point, the team analyzed the overall tradeoffs between travel-time uncertainty and the other primary indicators of trip costs, namely average travel time and monetary cost. The team followed Black and Towriss (1993) by using the standard deviation of travel time as the measure of uncertainty and estimated a model in which this variable was added to the conventional time and cost variables. This gave, for example, an estimate of the dollar cost implicitly assigned by travelers to travel-time uncertainty. One could also observe how the cost of uncertainty is related to trip purpose and socioeconomic factors.

The research team then went on to estimate the more complete model incorporating the scheduling variables in Equation 2. This model depicts how travelers simultaneously account for the following factors in making their choices: average travel time, *E(T)*; average number of minutes arriving early, *E(SDE)*; average number of minutes arriving late, *E(SDL)*; probability of arriving late, P_L; standard deviation of travel time, *SD(T)*; and money cost, *M*. As in Chapter 2, the research team assumed that user-perceived cost is linear in the underlying variables, so that expected cost is given by the following simple extension of Equation 2:

$$EC_s = \alpha E(T) + \beta E(SDE) + \gamma E(SDL) + \theta P_L + \sigma SD(T). \tag{8}$$

Travel-time uncertainty *SD(T)* appears in the equation, but one can expect it to be much less important now because most of the effects of uncertainty are separately accounted for in the terms involving *E(SDE)*, *E(SDL)*, and P_L. In fact, if scheduling considerations are the sole reason for disliking travel-time uncertainty, the value of σ will be zero. As shall be seen, this is the most likely interpretation of the results.

All the variables in Equation 8 can be calculated for each of the alternatives posed in pairs to the respondents. For example, consider Choice A in the sample question for Experiment #1 shown in Chapter 3. Let X_1–X_5 be the five possible values given for arrival time, where "early" is coded as a negative number: in the example these values are –7, –4, –1, 5, and 9. Mean travel time *E(T)* and money cost *M* are given directly in the question; in the example they are 9 min and \$0.25. The standard deviation *SD(T)* is calculated from the distribution of arrival times as follows:

$$SD(T) = \sqrt{\frac{1}{5}\sum_{i=1}^{5}[T_i - E(T)]^2} = \sqrt{\frac{1}{5}\sum_{i=1}^{5}(X_i - \bar{X})^2} \tag{9}$$

where T_1–T_5 are the five possible travel times implied by the choices provided.[1] Lateness probability is just the fraction of the five possible arrivals that are late, namely 0.4. As for expected *SDE* and *SDL*, recall that *SDE* is defined to be positive for early arrivals and zero otherwise; while *SDL* is positive for late arrivals and zero otherwise. Averaging over the five possibilities, one finds the following:

$$E(SDE) = (7 + 4 + 1 + 0 + 0)/5 = 2.4 \text{ min}$$

$$E(SDL) = (0 + 0 + 0 + 5 + 9)/5 = 2.8 \text{ min}$$

The *average* values of both early and late arrivals are positive, even though one never arrives early and late on the same day. It is travel-time uncertainty that makes this occur, and this is precisely why these expected schedule delay variables capture some of the cost of uncertainty. Because travel time is uncertain, a given departure time may result in being sometimes early, sometimes late, for work; the larger the standard deviation, the larger this effect, causing the costs of early and late arrivals to rise with uncertainty.

The coefficients of Equation 8 can be estimated from a standard binary logit or probit model. As in Section 5.1, one forms a choice index or "systematic utility" from the expected scheduling cost C_s in a manner analogous to Equation 5:

$$\begin{aligned} V &= \beta_M \cdot (C_s + M) \\ &= \beta_{tt}E(T) + \beta_{SDE}E(SDE) + \beta_{SDL}E(SDL) + \beta_{PL}P_L \\ &\quad + \beta_{std}SD(T) + \beta_M M. \end{aligned} \tag{10}$$

The five coefficients of Equation 8 are the ratios of β_{tt}, β_{SDE}, β_{SDL}, β_{PL}, and β_{std}, respectively, to β_M (i.e., each of the implicit cost parameters in Equation 8 is measured as a marginal rate of substitution between the corresponding variable and monetary cost). For example, the (unit) value of expected travel time is β_{tt}/β_M, in units of dollars per minute, corresponding to the usual concept of value of time as discussed in the previous chapter. The value of schedule delay early (i.e., the willingness to pay to avoid arriving earlier than the preferred time), is β_{SDE}/β_M, measured in dollars per minute of early arrival. Late arrival involves two costs—a discrete penalty of β_{PL}/β_M for arriving late plus an additional penalty of β_{SDL}/β_M per minute; these are self-perceived costs that may or may not incorporate actual penalties imposed by an employer. If travel-time uncertainty imposes any additional costs beyond these, they are measured by β_{std}/β_M per minute of standard deviation of travel time.

In the work that follows, this specification is enriched to allow trip purpose and socioeconomic variables to affect the unit costs placed by the user on these variables. As shall be seen, it also became necessary to modify Equation 10 slightly to better reflect certain complications of people's behavior, namely a tendency to prefer arriving a few minutes before work starts and a tendency to especially avoid arriving beyond an understood tolerance for lateness. These modifications are straightforward and are explained in connection with the results that follow.

5.2.1 Models With Scheduling Costs Implicit

It is useful first to estimate the model of Equation 10 omitting the scheduling variables *E(SDE)*, *E(SDL)*, and P_L. That way, the variable *SD(T)* captures all the ill effects of travel-time uncertainty, whatever their source. This model is comparable to those estimated by Black and Towriss (1993).

The result is shown in the first column of Table 22. The implied value of mean travel time, β_{tt}/β_M, is (0.0851/1.3037) = \$0.0653 per minute, or \$3.92 per hour. This is low compared with most estimates of value of time. The explanation for the

[1] Because *E(T)* is given as a datum, the implied travel time is $T_i = E(T) + (X_i - \bar{X})$, where $\bar{X}$ is the average of the five values of X_i. This can be verified easily by taking the expectation (i.e., average) of both sides, because the expectation of $(X_i - \bar{X})$ is zero. Thus it immediately follows that $T_i - E(T) = X_i - \bar{X}$, an equivalence used in Equation 9.

TABLE 22 Models based on standard deviation of travel time

Explanatory variables	Model 11	Model 12	Model 13
Mean travel time (tt) E(T)	−.08505 (−13.588)	−.1325 (−6.803)	−.1114 (−13.369)
Standard deviation of travel time (std) SD(T)	−.2738 (−23.292)	-.2461 (−7.794)	−.2746 (−16.424)
Lower income*travel time LOI*tt Lower income*std. dev. travel time LOI*std	— —	.0563 (4.273) .0468 (2.194)	.0601 (4.776) .0553 (2.667)
Work trip * travel time W*tt Work trip*std. dev. travel time W*std	— —	−.0213 (−1.658) −.0444 (−2.110)	— −.0628 (−3.128)
Number of adults in the household * tt AD*tt Number of adults * std. dev. travel time AD*tt	— —	.0144 (2.033) −.0129 (−1.117)	
Number of 0–15 year old children * tt CH*tt Number of children * std. dev. travel time CH*std	— —	−.0071 (−1.221) −.0083 (−0.876)	
Monetary cost M	−1.3037 (−29.463)	−1.3182 (−27.884)	−1.3102 (−27.959)
Sample size (N)	5630	4981	5043
Log likelihood Log likelihood on N = 4981	−3251.956 −2873.742	−2846.604 −2846.604	−2891.297 −2851.592
p-value for likelihood ratio test against: Model 11 Model 13	 — —	 .0000 .0759	 .0000 —

Note: t-statistics (shown in parentheses) are uncorrected for dependence among observations from the same respondent (see text).

low value is the same as in the previous chapter, but the explanation applies with even more force here: given that respondents need to evaluate the implications of alternative travel-time distributions, they are led to pay less attention to average travel time, which is just one of seven numbers presented to them for each scenario. (The same argument does not apply to cost because charging for highways is a salient issue in the region and people are keenly aware of its importance as a policy issue.)

The implied unit cost of travel-time uncertainty is (0.2738/1.3037) = \$0.210 per minute of standard deviation. This is about twice the value of time estimated in Section 5.1, and 1.31 times the consensus value of time, mentioned in Chapter 2, equal to half the wage rate. (Recall that the median wage rate for employed people in the sample was estimated in Chapter 4 to be \$19.20 per hour, or \$0.32 per minute.) This ratio of 1.31 between the unit costs of uncertainty and mean travel time is probably a reasonable point of comparison with previous studies. Black and Towriss (1993) call this ratio the "reliability ratio," and their estimate is 0.7 (p. 31). Small et al. (1995), using a comparable specification, estimate the reliability ratio to be 1.27. The closeness of this latter estimate to that derived from the current study suggests that people's evaluation of travel-time uncertainty shows consistency across at least moderate differences in question format. One can conclude that 1.30 is a reasonable ratio to assume for the relative cost of standard deviation and mean travel time when scheduling costs are not separately accounted for.

Taking employment status, trip purpose, and socioeconomic characteristics into account diminishes the sample size by about 12 percent because of missing data, especially on the question about income. Surprisingly, Model 12 demonstrates that very few interactions with these variables are statistically significant, with three likely exceptions: lower household income (the variable LOI is a dummy variable defined as one for incomes \$45,000 or less, zero otherwise) reduces both the value of travel time and the value of reliability, and making a work trip increases the value of reliability. All three of these effects are very plausible, and they are included without the others in Model 13, which provides the best summary model with scheduling costs included implicitly in the value of reliability.

TABLE 23 Values of reliability implied by Models 11 and 13

	Value of reliability ($ per minute std. dev.)	
	Model 11	Model 13
Work trip, higher income	0.210	0.258
Work trip, lower income	0.210	0.215
Non-work trip, higher income	0.210	0.210
Non-work trip, lower income	0.210	0.167

To illustrate the implications of Model 13, the last column of Table 23 shows how the value of reliability varies with income and trip purpose. For example, higher income commuters to work value reliability at (0.2746+0.0628)/1.3102 = $0.258 per minute.

The research team also tried interacting income and trip purpose with cost rather than the time measures, but that version of the model fits considerably less well.

5.2.2 Models With Scheduling Costs Explicit

Table 24 shows the results when the more complete model accounting for scheduling costs is estimated. Two modifications to Equation 10 were found to substantially improve the model's explanatory power. One is allowing the underlying cost of Equation 1 to be quadratic rather than linear in *SDE*; to accomplish this, one calculates the expected value of SDE^2 in a manner analogous to calculating the expected value of *SDE*, and include it as a variable. This leads to a weak and slightly positive coefficient on $E(SDE)$ and a strongly significant coefficient on $E(SDE^2)$. The magnitudes of the coefficients imply that as *SDE* increases from zero, there is a benefit up to about $SDE = 3$ min, followed by a strong disbenefit. The explanation is simple: people prefer to allow a small margin of error, and furthermore people's aversion to arriving early increases non-linearly as they find themselves more and more out of step with their desired activity schedule at the trip's destination. (A specification that fits somewhat less well allows the cost of *SDE* to be zero for the first few minutes early, then rise linearly for additional minutes early.)

Similarly, people's disbenefit because of arriving late may increase more than proportionally as they become later and later. However, the research team found that specifying a quadratic term in *SDL* was inferior to allowing for an additional penalty for lateness beyond a particular point that corresponds with their answer to the question: "How much later than [the official starting time] can you normally arrive at work without it having an impact on your job status or take-home pay?" We calculated for each sample member an additional variable equal to the probability P_{XL} that the travel-time distribution presented would result in arrival beyond that point. It can be regarded as the expectation of a dummy

TABLE 24 Models based on scheduling variables and trip purpose

Explanatory variables:	Model 14	Model 15
Mean travel time (tt)	−.0480	−.0578
E(T)	(−4.950)	(−7.094)
Expected schedule delay early	.0398	.0236
E(SDE)	(1.668)	(1.037)
Exp. schedule delay early squared	−.006054	−.005173
$E[(SDE)^2]$	(−6.114)	(−6.013)
Probability of late arrival	−2.1264	−1.8487
P_L	(−5.754)	(−4.790)
Work trip*Prob. of late arrival	—	−1.0984
$W*P_L$		(−2.463)
Expected schedule delay late	−.4033	−.3181
E(SDL)	(−6.548)	(−13.380)
Probability of extra late arrival	−1.6614	−1.0030
P_{XL}	(−4.231)	(−2.139)
Standard deviation of travel time (std)	.0665	—
SD(T)	(1.682)	
Monetary cost	−.9060	−1.0256
M	(−10.511)	(−19.848)
Sample size (N)	5630	5624
Log likelihood	−3161.842	−3156.031
p-value for lik. Ratio test against Model 11:	0.0000	NA

Note: t-statistics (shown in parentheses) are uncorrected for dependence among observations from the same respondent (see text).

variable, D_{XL} equal to one in the event that arrival is later than this stated amount. So for example, returning to the example used earlier in this chapter, suppose a person responds that he or she could arrive 5 min later than the official work start time, which in turn is 2 min later than the "preferred arrival time." Such a person would incur the extra penalty (denoted by the coefficient of D_{XL}) whenever $X_i > 7$, which happens in the example with a one-in-five chance; therefore the probability of "extra late arrival," P_{XL}, is 0.2. This penalty applies in addition to those represented by the variables P_L and *E(SDL)*. The variable P_{XL} applies only to work trips and is set to zero for other trips.

This model is estimated as Model 14 in Table 24. When scheduling costs are explicitly accounted for, the variable measuring the standard deviation of travel time (i.e., $SD(T)$) no longer has explanatory power. It is small in magnitude, statistically insignificant, and not of the expected sign. The researchers found this true in all models containing the scheduling variables. The research team concluded that the possibility mentioned earlier was, in fact, realized in the sample: scheduling costs account for all the aversion to travel-time uncertainty. Therefore, in models with a fully specified set of scheduling costs, it is unnecessary to add an additional cost for unreliability of travel. For this reason the variable *SD(T)* is omitted from further models of this type.

Experimentation with dummy variables for employment status and trip purpose revealed, as expected, that work trips have a higher late-arrival penalty than other trips. Other coefficients did not show statistically significant interactions with employment status or trip purpose. As a result, Model 15 is probably the most reliable estimate of these effects without taking into account socioeconomic characteristics.

The marginal tradeoffs against monetary cost implicit in Model 15 are shown in the first column of results in Table 25. They are estimates of the underlying cost coefficients of Equation 2, so are described as the (marginal) costs of *SDE*, D_L (the dummy variable indicating late arrival), *SDL*, and dummy variable D_{XL}. This calculation consists of ratios of coefficients, as described earlier, with the exception of the marginal cost of *SDE* which, because *SDE* appears as a quadratic in the basic scheduling cost equation, is given by $[\beta_{SDE} + 2(SDE)\beta_{SDE2}]/\beta_M$. (The numerator is the derivative of $\beta_{SDE}(SDE) + \beta_{SDE2}(SDE)^2$ with respect to *SDE*.) The marginal cost of *SDE* therefore rises with *SDE*, as seen in the table.

These marginal tradeoffs shown in Table 25 display strikingly plausible behavior. People are willing to pay 3 to 13 cents to avoid arriving at work a minute earlier, if they are already arriving within the range of 5 to 15 min early. Late arrivals are treated as a more serious matter. Even a person making a non-work trip will pay \$1.80 plus 31 cents per minute to avoid being late. A commuter will pay more: \$2.87 plus 31 cents per minute to avoid being late, plus an additional \$0.98 not to be so late as to affect job status or take-home pay. It is not surprising, given these underlying considerations, that the simple Model 11 showed a substantial willingness to pay for a more reliable travel environment.

As with the models of Section 5.1, one would expect these tradeoffs to be influenced by demographic or economic considerations. Table 26 shows further elaboration of Model 15 obtained by interacting key trip characteristics with socioeconomic indicators. The underlying assumption governing the interactions shown is that family size and income affect the payoffs to arranging schedules in such a way that late arrivals sometimes occur, as well as the resulting penalties. Other interactions, including a continuous income variable (like that used in Section 5.1) and various carpooling combinations, were tried without finding anything statistically significant. Among those shown in Table 26, only two give very compelling evidence: people are more resistant to being late if they have children, and people in lower income households are less resistant to arriving early.

Model 18 includes two sets of interactions: family size with lateness probability, and income with expected amount of lateness. Here, the implied costs of various marginal

TABLE 25 Marginal values of travel time components (\$)

	Model 15 (5624 obs.)	Model 18 (4981 observations)			
		1 adult No children High income	2 adults No children High income	2 adults 2 children High income	2 adults 2 children Low income
SDE at:					
SDE = 5 min	0.028/min	0.032/min	0.032/min	0.032/min	0.032/min
SDE = 10 min	0.078/min	0.080/min	0.080/min	0.080/min	0.080/min
SDE = 15 min	0.128/min	0.129/min	0.129/min	0.129/min	0.129/min
Late arrival (D_L):					
Work trips	2.87	3.27	2.89	3.87	3.87
Non-work trips	1.80	2.22	1.84	2.82	2.82
SDL	0.310/min	0.360/min	0.360/min	0.360/min	0.231/min
Extra late arrival (D_{XL})	0.98	0.77	0.77	0.77	0.77

TABLE 26 Further development of Model 15 based on household composition and income

Explanatory variables	Model 15	Model 16	Model 17	Model 18
Mean travel time (tt)	−.0578	−.0604	−.080	−.0815
E(T)	(−7.094)	(−7.341)	(−7.994)	(−8.057)
Lower income*travel time	—	—	.0519	.0482
LOI*tt			(3.993)	(3.666)
Expected schedule delay early	.0236	.0210	.0199	.0175
E(SDE)	(1.037)	(0.934)	(0.835)	(0.729)
Exp. Schedule delay early sq.	−.005173	−.005155	−.0050163	−.0050
$E[(SDE)^2]$	(−6.013)	(−5.913)	(−5.418)	(−5.344)
Probability of late arrival	−1.8487	−2.2897	−1.9778	−2.6699
P_L	(−4.790)	(−3.854)	(−4.820)	(−4.259)
Work trip*Prob. of late arrival	−1.0984	−1.0834	−1.0820	−1.0867
$W*P_L$	(−2.463)	(−2.495)	(−2.264)	(−2.256)
Number of adults * P_L	—	.2742	—	.3892
$AD*P_L$		(1.402)		(1.892)
Number of children * P_L	—	−.4366	—	−.5048
$CH*P_L$		(−2.495)		(−2.564)
Expected schedule delay late	−.3181	−.3188	−.3770	−.3705
E(SDL)	(−13.380)	(−13.247)	(−12.091)	(−11.782)
Lower income*E(SDL)	—	—	.1428	.1325
LOI*E(SDL)			(3.661)	(3.335)
Probability of extra late arrival	−1.0030	−.8794	−.9065	−.7902
P_{XL}	(-2.139)	(-1.868)	(−1.802)	(−1.565)
Monetary cost	−1.0256	−1.0361	−1.0820	−1.0296
M	(−19.848)	(−19.852)	(−18.642)	(−18.722)
Sample size (N)	5624	5550	5043	4981
Log likelihood	−3156.031	−3106.718	−2809.314	−2766.905
Log likelihood on N = 4981	−2791.980		−2772.107	−2766.905

Note: t-statistics (shown in parentheses) are uncorrected for dependence among observations from the same respondent (see text).

changes in trip characteristics differ by family status and income, so one can best understand the results by calculating these costs for several different situations. This is done in the last four columns of Table 25. Generally, the magnitudes and kinds of variation seem plausible. It is not obvious why people with children are more averse to late arrival, but it may be because they cannot stay late at the end of the day to make up for late arrival, because of child care responsibilities. Overall, the results in Table 25 seem to provide a good guideline to how the perceived costs of undesirable travel schedules vary by family status, income, and trip purpose.

5.2.3 Recommendations for Practice

Table 25 summarizes the underlying motivations for why people value travel reliability. Given sufficient data and modeling effort, one can apply these numbers to a model of people's choice of when to travel, and thereby derive the benefits from improving the reliability of their travel environment. An example of this approach, although with a simpler model estimated on a smaller data set, is the paper by Noland et al. (1998). This approach enables the analyst to provide a complete description and evaluation of the effects of changes in travel reliability.

For a more rough-and-ready analysis, without explicitly modeling people's decisions about trip scheduling, a good measure of the overall value of reliability is that derived from Model 11, namely $0.21 per minute of standard deviation. This value should be adjusted to reflect the price level and income prevailing in the situation under consideration. A simple way to do this is to apply the estimate that the value of reliability just quoted is equal to 1.31 times the "consensus" value of time that would be obtained from calculating half the wage rate expressed per minute. If one can distinguish between low- and high-income groups and between work and non-work trips, then the values shown in the last column of Table 23 are appropriate.

Once scheduling costs are accounted for, there is no demonstrable additional cost of travel-time uncertainty. All the adverse effects of an unreliable travel environment seem to be included in the scheduling costs. From an analytical point of view, therefore, one can choose either the more sophisticated models summarized by Tables 24 through 26 or the simple models of Tables 22 and 23; but the effects in the two types of model should not be added together.

CHAPTER 6

FREIGHT TRAVEL SURVEY: FINDINGS AND ANALYSIS

Congestion contributes not only to making travel times longer, but also more unpredictable. This unpredictability can hinder just-in-time inventory management programs and even interrupt freight-dependent production processes. As a result, freight shippers are very likely to attach a dollar value to any increases in predictability that would help them avoid the costs associated with unreliable travel times.

This chapter presents the results of a survey of freight carriers on travel-time predictability. According to the results, freight carriers do not assign a significant value to increases in travel-time predictability. There are various reasons why the results are inconclusive, not the least of which are the small sample of carriers surveyed and the inability to control for time-sensitive carrier characteristics. These and other issues are discussed below.

The research hypothesis, survey methodology, a description of the choice model with travel-time predictability, the results, and the conclusions and recommendations are also presented below. The model is based on the hypothesis that freight carriers assign a value to the predictability of travel time, when controlling for other factors such as travel cost and mean travel time. This value of predictability can be derived from a stated preference survey administered to representatives of carrier firms, which is then used to estimate a logit model.

Transportation planners are increasingly concerned with congestion and, as a result, may already have information about the extent of congestion. In order to apply the tools developed here, they need to put this information into the form of estimates of how much of the observed traffic is at Level of Service E or F, and of estimates of the standard deviation of travel time. The latter is likely to be known only through special studies, as might be taken for example in connection with evaluating a major road improvement or a new HOV lane. In such studies, some rule of thumb developed in the literature, as explained in Section 2.2.2 (especially the studies by Black and Towriss, 1993; Bates et al., 1987; Chang and Stopher, 1981; and Foster, 1982) may prove to be useful starting points.

6.1 INDUSTRY SELECTION FOR SURVEY

The stated preference survey is an instrument used to define travel time valuation. Depending on the sensitivity of time preferences, the valuation of travel time will vary among carrier firms. Therefore, industries representative of these sensitivities were selected (i.e., highly time sensitive [HTS], moderate to high time sensitivity [MHTS], moderate to low time sensitivity [MLTS], and low time sensitivity [LTS]).

The industries chosen, based on the primary commodity carried, are as follows:

- HTS: agriculture/fresh produce,
- MHTS: building materials/cement/construction materials/aggregate,
- MLTS: bulk liquids/liquid petroleum/water, and
- LTS: household goods.

6.1.1 Agriculture/Fresh Produce

This industry is extremely time-sensitive as a result of the perishability of the commodities carried. Shipments are generally picked up from a field site and delivered to a warehouse. In some cases, shipments are loaded and unloaded at field sites and are also termed very time-sensitive. Commodities, such as seedlings, are required at precise times as determined by weather and labor conditions. If a shipment of seedlings is late, the carrier firm is often responsible for the labor crew's wages over the period delayed.

6.1.2 Building Materials/Cement/Construction Materials/Aggregate

Commodities delivered in this industry range from medium to high time sensitivities. Products such as heavy equipment or dirt have a lower time sensitivity than a product such as ready-mix cement. Although carrier firms may keep labor waiting if equipment is late, the commodity is not damaged by time delays; the firm normally incurs only the cost of reputational qualities. However, ready mix is very time-sensitive, so much so that a shipment delayed often becomes useless for its intended use. The load then becomes the responsibility of the carrier firm, incurring the associated costs.

6.1.3 Bulk Liquids/Liquid Petroleum/Water

The industry of bulk liquid shipments experiences moderate to low time sensitivity. Generally, the commodity shipped is not time-sensitive itself, rather the recipient. Most shipments are loaded at a refinery and delivered to a service station. If the service stations receive a delayed shipment, the carrier firm is usually responsible for the monetary value of product that normally is sold during the period delayed.

6.1.4 Household Goods

In general, the industry of household goods shipments is the least time-sensitive of those industries surveyed. Most shipment deliveries were found to be acceptable if within the same day of pre-scheduled arrival. However, carrier firms generally delivered shipments at or very near the pre-scheduled time of arrival.

6.2 SURVEY DESIGN, PROCESS, AND FINDINGS

A total of 168 carriers was selected from among four industry groups from approximately 2,000 carrier firms in California. As discussed earlier, these four groups of industries were assumed to have a range of sensitivities to transit time predictability. Because of budget limitation, a final sample of 20 carriers was randomly selected from these 168 firms for the surveys, with 5 from each industry group.

The stated preference experiments are designed from the carrier's point of view. In particular, they are designed to evaluate how the carrier would trade off freight costs and improvements in transit time reliability in selecting how early to depart from the origin for a typical shipment that has a desired arrival time at the destination.

The surveys were implemented with a telephone interview and a set of stated preference experiments. The telephone interview first identified within each firm an individual with shipment-specific information as the respondent. (The position of each respondent is given in Table 27.) Several characteristics of the firm were also obtained. Once the telephone interview was completed, the respondents were faxed the stated preference experiments and asked to phone in their responses to the experiments. Each stated preference survey consisted of six experiments, each of which was a two-alternative choice for a shipment. Each alternative was characterized by carrier cost, average transit time, and a five-point distribution of schedule delays. A total of 20 telephone interviews and 120 stated preference experiments were completed.

An example of a stated preference experiment is presented in Figure 1, in which a respondent has to choose between two alternatives, each with its own estimated average transit time, freight cost, and distribution of time delays. The average transit time in the experiment was chosen such that it was comparable to the average transit times the respondents actually faced in their jobs. The distribution of transit times among respondents is given in Table 28.

The time delays followed a log-normal distribution, where the standard deviation of the distributions was made to vary between experiments. In effect, the respondents trade off among costs, the mean of the distribution (average transit time) and its standard deviation (which is represented by the five-point distribution) in choosing between alternatives.

Several characteristics were obtained for each carrier, including sensitivity to travel time predictability as represented by primary commodities carried, use of just-in-time inventory management by its most frequent customer; and others. These characteristics are hypothesized to affect how much a carrier would value improvements in transit time and predictability. However, they were not used in the following analysis because of the small sample size. The actual survey results are presented in Appendix G.

In the design of the stated preference surveys, four variables are involved:

- C: Cost to the carrier in dollars
- T: Average transit time in hours
- CV: Coefficient of variation of transit time
- T_d: Time between departure and desired arrival in hours

C and T appeared explicitly in the stated preference survey. CV and T_d, along with T, were used in generating the five-point distribution of schedule delay, SD_i ($i = 1 - 5$). The SD_i ($i = 1 - 5$) were generated in three steps which are detailed in Appendix H.

TABLE 27 Frequency of respondent position

Position	Frequency
President/Vice President	4
Dispatcher	4
Bookkeeper	3
Owner	2
General Manager	2
Warehouse Manager	1
Safety Manager	1
Billing Clerk	1
Office Manager	1

6.3 ANALYSIS OF SURVEY RESULTS

6.3.1 Choice Model with Travel-Time Predictability

The choice between alternatives, based on the attributes of each alternative (e.g., freight costs, average transit time, and distribution of schedule delays) was assumed to be described by a conditional logit model. According to this model, a respondent chooses between two alternatives (0 and 1, with 1 being preferred), depending on which of the two alternatives scores higher on each of several favorable attributes (in

Please Circle Either **Choice A** or **Choice B**

Choice A	**Choice B**
Average Transit Time: 30 minutes	Average Transit Time: 23 minutes
The shipment has an equal chance of arriving at any of the following times: 7 minutes early 5 minutes early 3 minutes early 2 minutes early 1 minute late	The shipment has an equal chance of arriving at any of the following times: 15 minutes early 12 minutes early 9 minutes early 7 minutes early 3 minutes early
Freight cost: $50	Freight Cost: $50

Figure 1. Example of survey question/experiment.

this case, predictability) or lower on each of several unfavorable attributes (e.g., average transit time or freight costs). The relative value assigned to each attribute is ultimately determined by the statistical estimation of the logit model based on several experiments.

In this analysis, each experiment involves a single choice between two alternatives. Each alternative is characterized by a set of attributes, x_{ji}, where i indexes individual experiments. There is a single parameter vector, β, which measures the values of each attribute. The model underlying the stated preference data is assumed to be the following:

$$U_{jt} = \beta' x_{ji} + \varepsilon_{ji}, j = 1, 2 \tag{11}$$

The individual terms, $(\varepsilon_{1i}, \varepsilon_{2i})$, are random and assumed to be independently distributed, each with an extreme value (Gumbel) distribution. Under these assumptions, the probability that alternative j is chosen in experiment i, P_{ji}, is:

$$P_{ji} = \frac{\exp(\beta' x_{ji})}{\exp(\beta' x_{1i}) + \exp(\beta' x_{2i})} \tag{12}$$

Four separate models were estimated, each with a different set of attributes. The first one included transit time (T), cost (C), and standard deviation of transit time (S). The second and third sets replaced standard deviation in the first one by coefficient of variation[1] of transit time (CV) and probability of being late (P_L), respectively. The last one added expected schedule delay early (SDE) and schedule delay late (SDL) to the third one. Except for the third one, the other specifications followed those used in the passenger survey analysis.

The standard deviation, coefficient of variation, probability of being late, and the expected schedule delay were derived from the log-normal distribution of travel times presented to each respondent. The derivations of these variables is presented in Appendix H.

TABLE 28 Frequency of transit time

Segments	Range (hours)	Frequency
1	≤1	4
2	1–2	5
3	2–3	6
4	3–4	1
5	4–5	2
6	5–6	1
7	6–7	0
8	7–8	2

6.3.2 Interpretation of the Results

The model was estimated with the maximum likelihood method for each of the four specifications. Because of the small sample size, no disaggregation by the four industry groups or other carrier characteristics was done. Table 29 shows the estimation results. Both carrier cost (C) and transit time (T) are significant in the first three specifications. When variables measuring schedule delays are added, carrier cost remains significant, but the sign on the coefficient for P_L becomes incorrect. The relative magnitudes of coefficients for SDE, SDL, and T are, as expected, in the following ascending order: SDE, T, and SDL. However, none of the variables that measure transit time predictability (CV, S, P_L) is significant. In addition, CV (in specification 1) and P_L (in specification 4) have incorrect signs.

Although the parameter estimates in Table 29 show whether the attributes are significant in explaining a respondent's choice of one alternative over another, they do not

[1] The coefficient of variation is equal to the standard error divided by the mean.

TABLE 29 Estimation results[a]

Independent Variables	Alternative Specifications 1	2	3	4
C: Cost (dollars)	−0.0120* (−3.750)	−0.0129* (−3.583)	−0.0122* (−4.067)	−0.0174* (−3.702)
T: Transit time (hours)	−2.3139* (−4.026)	−2.3502* (−4.022)	−1.7595** (−2.490)	−1.2788 (−0.843)
CV: Coefficient of variation	1.8654[b] (0.637)			
S: Standard deviation (hours)		−0.0919 (−0.078)		
P_L: Probability of being late			−1.1199 (−1.254)	0.9552[b] (0.873)
SDE: schedule delay early (hours)				-0.1540 (-0.102)
SDL: schedule delay late (hours)				-6.4611* (-2.812)
Log Likelihood				
no coefficients	-83.1777	-83.1777	-83.1777	-83.1777
with coefficients	-65.0698	-65.2701	-64.4643	-58.6094
Number of observations	120	120	120	120

[a] T-statistics are in parentheses and are not adjusted for repeated observations (six) from each respondent.
[b] Coefficient has an incorrect sign.
* Coefficient is significant at 1% level.
** Coefficient is significant at 5% level.

reflect the actual value, in dollar terms, of the attributes. The dollar values of each attribute are given in Table 30, only for those variables that were significant (in Table 29) in explaining the respondents' choices.

These values indicate that carriers on average value savings in transit time at $144.22 to $192.83 per hour and savings in schedule delay late at $371.33 per hour.

6.4 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

Although the results did confirm the importance of transit time and freight costs in shipping decisions, they failed to measure a significant value for changes in transit-time predictability. Several points should be kept in mind in interpreting these results:

TABLE 30 Value of improved performance (in dollars per unit)[a]

Independent Variables	Alternative Specifications 1	2	3	4
T: Transit time (hours)	192.83	182.19	144.22	
CV: Coefficient of variation				
SD: Standard deviation (hours)				
P_L: Probability of being late				
SDE: schedule delay early (hours)				
SDL: schedule delay late (hours)				371.33

[a] Values are calculated from Table 29 only for those variables with a level of significance that is no less than 5%.

- The sample consisted of only 20 carriers.
- The characteristics of carriers were not controlled.
- Respondents expressed difficulties in understanding the cost variable, distribution of schedule delays, and hypothetical experiment.
- The design did not use simulations to adjust variable values.

In addition, the model could be improved by grounding it more firmly in a theoretical model of carrier behavior.

The current study could be improved in several ways in order to provide a better estimate of the value and significance of travel-time reliability in shipping decisions. These improvements are as follows:

- **Increase Sample Size.** A larger sample size would not only increase the precision of estimation, but would also allow one to control characteristics of carriers. Experience indicates that carriers who carry different types of commodities can value improvements in transit time or transit time predictability significantly differently.
- **Increase Comprehension of Stated Preference Experiments.** First, cover letters to respondents need to explain better the nature of stated preference experiments and definition of variables, particularly carrier costs. Second, telephone use should be retained for stated preference surveys, but more interaction is needed between the respondent and interviewer on what the experiments mean. Third, replacing a distribution of schedule delay with the probability of being late may help. Respondents expressed difficulties in understanding the concept of occurrence with equal chance. However, carriers understand well the concept of on-time performance, which is commonly measured by the probability of being not late. Not coincidentally, probability of being late had the greatest explanatory power of all of the variables used to measure transit-time predictability.
- **Adjust Variable Values with Simulations.** This was done for passenger travel. The purpose is to ensure that the design could recover a sensible range of coefficients and consequently a sensible range of ratios of the coefficients. These ratios measure how much carriers value improvements in transit time and transit-time predictability.
- **Develop a Theoretical Model of Carrier Behavior.** As shown in the literature review, reliability has been incorporated in four types of theoretical models of demand for freight transportation. These models consider reliability in terms of choices for mode, shipment size, or shipment frequency. None of them, however, considers reliability in terms of scheduling decisions. The specifications used in this analysis assumed that the theoretical framework for scheduling behavior by passengers is valid for scheduling decisions by carriers.

CHAPTER 7

TRAVEL-TIME SAVINGS AND PREDICTABILITY IN HIGHWAY USER-COST ESTIMATION

Time costs figure prominently in the economic evaluation of highway projects. The potential time savings from even a minor highway improvement can translate into significant user cost savings over the life of the highway facility. The MVA Consultancy and collaborators, in a 1987 study of road improvement projects, found that, on average, 80 percent of estimated highway project benefits stem from the projected dollar value of time savings—51 percent from savings in working time and 29 percent for non-working time (MVA Consultancy et al., 1987). Therefore, determining the appropriate "value of time" or, more precisely, the "value of time savings" from highway infrastructure improvements is paramount in the evaluation of highway investments.

Additional evidence supporting this conclusion was supplied in a 1994 study by Hickling Lewis Brod Inc. (HLB) for NCHRP. The study found that reducing uncertainty in the valuation of time is the key means to reducing overall uncertainty in user-cost estimation. For example, improved engineering analysis leading to a reduction in uncertainty in value of time estimates by 50 percent would reduce uncertainty in total user costs by more than 69 percent (HLB Decision Economics, Inc., 1994).

These research results indicate that any improvements/advancements that can be made with regard to valuing and measuring travel-time savings would be valuable. This study expands the knowledge of travel-time costs and represents a substantial step toward reducing uncertainty and improving user-cost analysis. Thus, the challenge is to incorporate these results into current tools for highway user-cost analysis in as timely a fashion as possible. The remainder of this section outlines the justification of, procedures for, and benefits of incorporating the results of this study into standard highway user-cost analysis applications (tools).

7.1 REDUCING USER-COST UNCERTAINTY

The 1994 HLB study brought together many experts to scrutinize and critique the major user-cost models and the application of travel-time cost estimates. These experts articulated what the shortcomings of existing models are. Additionally, the study established what the state of the art pertaining to travel-time costs and estimation was and where and how improvements could be made. The major concerns expressed by the panel in the HLB study are summarized as follows:

- **Link to the Wage Rate.** Traditional U.S. methodologies relate estimates of the value of time to some measure of wages plus overhead. United Kingdom and European practice have recently begun to de-emphasize the wage base and to link the value of time to life cycle characteristics of travelers. Researchers are exploring value differences between frequent and infrequent travelers, the effects of culture and ethnicity, and how time constraints (e.g., catching a plane or arriving at work on time) relate to a user's willingness to pay for reduction in travel time.
- **Variability.** Measuring only changes in average travel times omits important factors in valuing time savings. Measuring changes in travel time and understanding how those changes are reflected in long-range adjustments to trip making and freight handling is important to understanding the productivity effects of highway improvements.
- **Congestion.** Understanding congestion involves more than simply comparing the value of time spent in traffic in congested and uncongested situations. Travelers may be willing to pay more to avoid time spent in traveling through congested areas than to avoid time spent in free-flow travel. Moreover, although the onset of congestion may disrupt trip schedules, congestion is not universally unproductive and time spent in congested travel can be spent productively as well as unproductively.
- **Small Time Savings.** The current Red Book methodology favors valuing small time savings at a lower rate than larger time savings. Many experts favor valuing small and large time savings equally because no plausible evidence exists that small time savings are valued less than larger time savings. If time is a good like other goods, the marginal utility of travel-time savings would tend to decline rather than increase as the amount of time saved increased. Additionally, evidence suggests that people are adept at aggregating small time savings into useable amounts of time.
- **Discontinuities.** Discontinuities affect the valuation of paid driver time and may make the wage-based valuation system unreliable. Paid driver time should be valued directly at the additional revenue (or value) employers gain from shorter journeys. This may differ from the pro rata hourly wage rate for the time actually saved, because

the saving is less than that needed to complete an additional trip or to make an additional delivery.

- **Valuing Business Time.** Treating time as a resource that is consumed in travel leads to methods of valuing business time based on measures of the marginal production lost while travel is being undertaken. Thus estimating methodologies include factors for the unproductive issue of office space and other overhead factors as well as non-salary benefits paid to traveling employees. Some methods also net off the value of any work accomplished during travel. This approach assumes that business time spent traveling would otherwise be spent in fully productive work, as measured by the overall average cost of employment. Alternative approaches would seek empirical evidence on either what travelers would be willing to pay to reduce travel time (of various sorts), or what employers would be willing to pay to reduce employee time spent traveling.

This study directly addresses many of the concerns expressed by the panelists in the HLB study, especially concerning congestion and valuing business time and travel-time variability. For these reasons and for those stated earlier, incorporation of the results of this study into standard highway user-cost analyses is important and will go a long way toward reducing the uncertainty surrounding the valuation and measurement of travel-time savings.

7.2 INCORPORATING THE RESULTS INTO A USER-COST ANALYSIS FRAMEWORK

Highway user-costs reflect both the physical and economic effects of highway performance on highway users. The *physical effects* are speed and travel time, vehicle operating performance, accident rates, and rates of environmental emission. The *economic effects* reflect the economic value of time and delay, the costs of operating cars and trucks, the amount users are willing to pay for safer roads versus other kinds of social progress (i.e., the "economic value" of safety), and the value to the economy of cleaner air relative to the economic sacrifices required to obtain it.

Uncertainty is a key attribute of the physical effects, and the research reported here indicates that this is strongly reflected in the economic effects. Specifically, both passengers and freight carriers are strongly averse to the scheduling mismatches that occur because they cannot predict precisely what their travel time will be. For this reason, and perhaps others, they will pay a premium to avoid congestion and to achieve greater reliability in travel times.

The results of this study enable the user-cost analyst to quantify the economic values that such highway users place on changes in the amounts of time spent traveling under congested and uncongested conditions and in the degree of predictability of those travel times. For passengers, values are segmented by income, trip purpose, and total trip time; the recommended procedures are described in Sections 5.1.1 and 5.2.3. These procedures require a somewhat more detailed knowledge of the effects of the changes being evaluated than is sometimes included in evaluations of highway projects.

However, for passenger travel, a good approximation may be obtained by using the results of Model 1 (as summarized in Tables 19 and 20) and Model 11 (Table 23). Model 1 indicates that any reduction in travel time under congested conditions is valued, for the median trip of 26 min, at 2.75 times the value of all travel time.

Model 11 indicates that each minute of standard deviation is valued on average at $0.21, a figure which should be adjusted for differences in incomes or wage rates relative to the median values in this study (namely, annual household income of $55,000 and hourly wage of $19.20).

Sometimes even this level of detail may be more than can be achieved in a given project evaluation. In particular, existing demand forecasting methods rarely give the standard deviation of travel time on a link-by-link basis. For this reason, a simplified approach is recommended based on the judgment of the research team from the evidence of this study. That approach consists of *applying a mark-up factor of 2.5 to the value of time when the time savings are under highly congested conditions*. That is, the assumed value of time in a given assessment should be multiplied by 2.5 when applied to time savings that occur during congested peak periods. This mark-up factor is based primarily on the findings just described, plus the result that both passengers and freight carriers value time savings at least twice as highly as normally if those savings occur in a situation when they are in danger of arriving late.

This simple mark-up procedure should not be viewed as an adequate substitute for more thorough assessments of the effects of major highway projects or policies on the amount of travel time spent in congestion and on the predictability of that travel time. The research team believes that the user-cost analysis in project assessments will be greatly improved by developing techniques to estimate in some detail the effects on congested travel and reliability and fully incorporating the evidence presented here regarding users' evaluation of those effects.

APPENDIX A

ZIP CODE AREAS FOR PASSENGER SURVEY

91719	92665
91720	92669
91760	92670
92501	92686
92503	92687
92504	92806
92505	92807
92506	92808
92507	

APPENDIX B

PASSENGER PRE-SURVEY AND STATED PREFERENCE SURVEY

Copies under separate heading.

APPENDIX C

DESIGN OF STATED PREFERENCE ATTRIBUTE LEVELS

INTRODUCTION

Two stated preference designs were developed for the car travel survey for this project. The first experiment focused on tradeoffs between travel time, variability, departure time, and cost. The second experiment focused on congested and free-flow travel times as well as cost.

The design work was carried out in steps as follows

1. Develop simulation procedures;
2. Determine ranges of coefficients for simulation;
3. Select stated preference design;
4. Develop values for variables (cost, travel time, etc.);
5. Simulate experiment for each segment;
6. Review designs and values;
7. If necessary, repeat from step 3.

The aim of simulating the stated preference experiments was to ensure that the designs could recover a sensible range of coefficients and, consequently, a sensible range of ratios of the coefficients (i.e., ratio of time coefficient over cost coefficient, etc.). Step 7 could take the design work back to step 3 and/or step 4 until a satisfactory range of sensible ratios was successfully recovered.

Nine segments were involved. These segments split travelers into nine bands of total travel time. These segments are presented in Table C1. In both experiments, travel times were rounded to the nearest minute and cost of travel was rounded to the nearest 25 cents. The ranges of the coefficients used in the simulations are shown in Table C2.

FIRST STATED PREFERENCE EXPERIMENT: TRAVEL TIME AND VARIABILITY

This experiment included four variables as follows:

- Mean travel time,
- Standard deviation of mean travel time,
- Departure time shift, and
- Cost of travel.

Each variable was entered in the design at three levels, which resulted in 81 (i.e., 3^4) possible combinations or **treatments** (full factorial design). Because the nature of stated preference is to assign preferences between treatments, it is important not to present tasks between treatments where the preference is obvious; this is usually referred to as the problem of dominance. To avoid dominated choices, it is good practice to choose only a few treatments from the full factorial.

The strategy adopted was to set out the design in a series of rows such that any treatment in a given row would be dominated by at least one treatment in the row above and would dominate at least one treatment in the row below. Within any one row, none of the treatments would dominate the other treatments. The researchers then chose the row yielding the maximal set of non-dominated treatments, which for the 3^4 factorial contains 19 treatments. However, rather than use all the available 19, 7 of them were eliminated in order to build in a certain amount of correlation between the design variables for the purpose of "realism." Thus, 12 treatments were used.

The decision was made at the outset of the study to present to each respondent six pair-wise comparisons from the first stated preference experiment (and six from the second). Each of these comparisons involves 2 of the aforementioned 12 treatments. Thus there are ($^{12}C_2$)-66 possible pair-wise comparisons.

To generate random sets of 6 pair-wise comparisons from the 66 possibilities would be extremely complicated in the context of a mail-back experiment; therefore, it was agreed that the design should be fixed. However, to have a single set of 6 pair-wise comparisons would have been too restrictive and it would have been extremely difficult to estimate four coefficients over a reasonable range from such a limited exercise.

It was therefore decided to prepare "blocks" (effectively, predefined sets of 6 pair-wise comparisons). The procedure was that a different block of pair-wise comparisons would be given randomly to each respondent. In this way, the data collected would display sufficient variation while satisfying the overall objective of presenting each respondent with only 6 pair-wise comparisons.

During the design work, the researchers experimented with using both four blocks and two blocks of pair-wise comparisons. As a result of the simulations, it was decided that a set of two blocks would give satisfactory results.

Another issue was how to choose 6 pair-wise comparisons from the 12 treatments. The researchers experimented with two ways of choosing the sets: (1) by random selection from 12, without replacement, and (2) by a more considered approach having regard to the likely ranking of the 12 treatments and based on some reasonable expectations about the likely coefficients. The latter approach proved more successful in simulation. The two blocks of pair-wise choice were therefore chosen on this basis.

The final task of the design was to allocate appropriate values to the levels of the design variables. Although different values were used for each distance segment, general prin-

TABLE C1 Segments based on travel time bands

Segment No	Travel Time Band (minutes)	Assumed Mean Travel Time (minutes)
1	≤10	9
2	11–20	15
3	21–30	25
4	31–40	35
5	41–50	45
6	51–60	55
7	61–75	68
8	76–90	83
9	>90	110

ciples were adopted and only departed from when the simulation revealed problems.

For mean travel time, the value for the middle level was based on the travel time band of the current trip. The other two values were determined as follows:

- Low level = current − x ∗ (current − free flow)
- High level = current + y ∗ (current − free flow)

Using such a formula ensures that the variation of travel time about the base is realistic; in particular, it ensures that it does not fall below the "free-flow time." The free-flow time was based on a free-flow speed of 45 mph.

In most cases, x was selected to be 0.4 and y was selected to be 0.6 (as a general principle equal spacing was avoided because this restricts the power of the design). However, during the simulation work, these values were modified within some segments in order to improve the results.

The base cost of travel was calculated assuming an average cost of $0.12 per mile. The distance was estimated "in reverse" from the respondent's travel time. First, 5 min was allowed for access/egress purposes. Then, for the remaining time, an average speed of 33 mph was assumed. The resulting cost was used to provide the value for the low level of cost for each segment.

TABLE C2 Range of simulation coefficients

	Low	Medium	High
Cost	−0.5	−1.0	−2.0
Mean Travel Time	−0.05	−0.1	−0.25
Standard Deviation	−0.06	−0.13	−0.27
Departure Time	−0.025	−0.05	−0.1
Stop-go Time	−0.06	−0.13	−0.27

Note: Cost units are dollars and time units are minutes

For the middle and high levels, two further increments were calculated, not equally spaced. Arbitrarily, they were chosen in the ratio of 3:8 for most segments. This was changed slightly for some segments during the simulation process in order to improve the results. The high cost level increment was not allowed to exceed $3.00, and the low level could not fall below $0.50.

The lowest value of the departure time shift was 0, representing an expected on-time arrival. The other two values were chosen as percentages of the mean travel time (e.g., 5 percent and 15 percent). These percentages were slightly modified for some segments in order to achieve the best possible design. The departure time was used to calculate the distribution of travel times actually presented in the stated preference questions. This was done by adding the departure time and the mean travel time and subtracting each of the travel time distributions generated by the standard deviation. This would give the early arrival time (negative if arrival is late).

The standard deviation of the mean travel time was based on the coefficient of variation (*cv*). Three levels were set for the coefficient of variation: 0.1, 0.2, and 0.3.

In order to provide values for the standard deviation, the coefficents of variation were multiplied by the mean time for the treatment to which they related. Thus, supposing treatment k in the design had a level i for travel time and level j for *cv*, the standard deviation for the treatment would be obtained by multiplying the value for level j of *cv* by the value for level i of travel time.

The final design of the first stated preference experiment is included at the end of this section as generated for all nine segments.

SECOND STATED PREFERENCE EXPERIMENT: TRAVEL TIME AND CONGESTION

This experiment included three variables as follows:

- Mean travel time,
- Travel time under stop-go (congested) conditions, and
- Cost of travel.

The principles of the design followed lines similar to Experiment 1. Each variable had three levels, which gave a full factorial design of 27 treatments. In this case, the maximal non-dominated group contained seven treatments. To build in a certain measure of correlation, two of these were dropped, leaving five. From this, a block of six pair-wise comparisons was chosen.

Given that $^5C_2$ is only 10, the maximal set did not yield sufficient pair-wise comparisons to define a second block. For this reason, an additional six treatments were taken from the next non-dominated row and a further block of six pair-wise comparisons was chosen.

Thus overall, 11 treatments were used, 5 of them generating the first block of six pair-wise comparisons and the other six the second block. Each respondent was presented with a single block according to random selection.

The values of mean travel time and cost of travel were designed to be similar to the first stated preference experiment.

As with the *cv*, stop-go time was incorporated in the design as a factor; the three levels of the stop-go factor were set to 0.4, 0.5, and 0.8 as proportions of the travel time (though these factors were slightly modified within some segments in order to achieve the best design). To give the value of stop-go time for the experiment, the factor for the treatment needed to be multiplied by the mean travel time for the treatment.

The final design for all nine segments is presented at the end of this section.

DESIGN OF STATED PREFERENCE EXPERIMENTS:

SCODE example: S1B1 is travel time segment 1, block 1

EXPERIMENT #1

SCODE	COST1A	TIME1A	SDEV1A	DEP1A	COST1B	TIME1B	SDEV1B	DEP1B
S1B1	0.75	9	1	9	0.75	7	2	9
	1.50	7	1	9	0.25	9	2	9
	0.25	9	2	9	1.50	9	1	2
	0.25	9	4	2	0.75	9	4	0
	0.25	12	2	2	1.50	9	2	0
	0.75	12	2	0	0.25	12	4	0
S1B2	0.25	9	2	9	0.25	9	4	2
	0.25	12	2	2	0.75	9	1	9
	0.75	7	2	9	0.25	12	4	0
	0.75	9	4	0	0.75	12	2	0
	1.50	7	1	9	1.50	9	1	2
	1.50	7	2	2	1.50	9	2	0
S2B1	1.25	15	2	11	1.25	13	3	11
	2.00	13	1	11	0.75	15	3	11
	0.75	15	3	11	2.00	15	2	2
	0.75	15	5	2	1.25	15	5	0
	0.75	20	4	2	2.00	15	3	0
	1.25	20	4	0	0.75	20	6	0
S2B2	0.75	15	3	11	0.75	15	5	2
	0.75	20	4	2	1.25	15	2	11
	1.25	13	3	11	0.75	20	6	0
	1.25	15	5	0	1.25	20	4	0
	2.00	13	1	11	2.00	15	2	2
	2.00	13	3	2	2.00	15	3	0
S3B1	1.75	25	3	8	1.75	22	4	8
	2.50	22	2	8	1.25	25	5	8
	1.25	25	5	8	2.50	25	3	3
	1.25	25	8	3	1.75	25	8	0
	1.25	35	7	3	2.50	25	5	0
	1.75	35	7	0	1.25	35	11	0
S3B2	1.25	25	5	8	1.25	25	8	3
	1.25	35	7	3	1.75	25	3	8
	1.75	22	4	8	1.25	35	11	0
	1.75	25	8	0	1.75	35	7	0
	2.50	22	2	8	2.50	25	3	3
	2.50	22	4	3	2.50	25	5	0
S4B1	2.75	35	4	9	2.75	32	6	9
	4.00	32	3	9	2.00	35	7	9
	2.00	35	7	9	4.00	35	4	2
	2.00	35	11	2	2.75	35	11	0
	2.00	41	8	2	4.00	35	7	0
	2.75	41	8	0	2.00	41	12	0
S4B2	2.00	35	7	9	2.00	35	11	2
	2.00	41	8	2	2.75	35	4	9
	2.75	32	6	9	2.00	41	12	0
	2.75	35	11	0	2.75	41	8	0
	4.00	32	3	9	4.00	35	4	2
	4.00	32	6	2	4.00	35	7	0

EXPERIMENT #1 ***(continued)***

SCODE	COST1A	TIME1A	SDEV1A	DEP1A	COST1B	TIME1B	SDEV1B	DEP1B
S5B1	3.50	45	5	11	3.50	41	8	11
	4.75	41	4	11	2.75	45	9	11
	2.75	45	9	11	4.75	45	5	3
	2.75	45	14	3	3.50	45	14	0
	2.75	54	11	3	4.75	45	9	0
	3.50	54	11	0	2.75	54	16	0
S5B2	2.75	45	9	11	2.75	45	14	3
	2.75	54	11	3	3.50	45	5	11
	3.50	41	8	11	2.75	54	16	0
	3.50	45	14	0	3.50	54	11	0
	4.75	41	4	11	4.75	45	5	0
	4.75	41	8	3	4.75	45	9	0
S6B1	4.25	55	6	14	4.25	50	10	14
	6.00	50	5	14	3.25	55	11	14
	3.25	55	11	14	6.00	55	6	4
	3.25	55	17	4	4.25	55	17	0
	3.25	66	13	4	6.00	55	11	0
	4.25	66	13	0	3.25	66	20	0
S6B2	3.25	55	11	14	3.25	55	17	4
	3.25	66	13	4	4.25	55	6	14
	4.25	50	10	14	3.25	66	20	0
	4.25	55	17	0	4.25	66	13	0
	6.00	50	5	14	6.00	55	6	4
	6.00	50	10	4	6.00	55	11	0
S7B1	5.25	68	7	17	5.25	61	12	17
	7.25	61	6	17	4.25	68	14	17
	4.25	68	14	17	7.25	68	7	5
	4.25	68	20	5	5.25	68	20	0
	4.25	78	16	5	7.25	68	14	0
	5.25	78	16	0	4.25	78	23	0
S7B2	4.25	68	14	17	4.25	68	20	5
	4.25	78	16	5	5.25	68	7	17
	5.25	61	12	17	4.25	78	23	0
	5.25	68	20	0	5.25	78	16	0
	7.25	61	6	17	7.25	68	7	5
	7.25	61	12	5	7.25	68	14	0
S8B1	6.25	83	8	17	6.25	74	15	17
	8.00	74	7	17	5.00	83	17	17
	5.00	83	17	17	8.00	83	8	6
	5.00	83	25	6	6.25	83	25	0
	5.00	95	19	6	8.00	83	17	0
	6.25	95	19	0	5.00	95	29	0
S8B2	5.00	83	17	17	5.00	83	25	6
	5.00	95	19	6	6.25	83	8	17
	6.25	74	15	17	5.00	95	29	0
	6.25	83	25	0	6.25	95	19	0
	8.00	74	7	17	8.00	83	8	6
	8.00	74	15	6	8.00	83	17	0

EXPERIMENT #1 *(continued)*

SCODE	COST1A	TIME1A	SDEV1A	DEP1A	COST1B	TIME1B	SDEV1B	DEP1B
S9B1	8.00	110	11	17	8.00	99	20	17
	10.00	99	10	17	7.00	110	22	17
	7.00	110	22	17	10.00	110	11	6
	7.00	110	33	6	8.00	110	33	0
	7.00	127	25	6	10.00	110	22	0
	8.00	127	25	0	7.00	127	38	0
S9B2	7.00	110	22	17	7.00	110	33	6
	7.00	127	25	6	8.00	110	11	17
	8.00	99	20	17	7.00	127	38	0
	8.00	110	33	0	8.00	127	25	0
	10.00	99	10	17	10.00	110	11	6
	10.00	99	20	6	10.00	110	22	0

EXPERIMENT #1—STANDARD DEVIATIONS

SCODE	SD1A	SD2A	SD3A	SD4A	SD5A	SD1B	SD2B	SD3B	SD4B	SD5B
S1B1	8	8	9	9	11	5	6	7	8	10
	6	6	7	7	9	7	8	9	10	12
	7	8	9	10	12	8	8	9	9	11
	5	6	8	10	15	5	6	8	10	15
	10	11	12	13	15	7	8	9	10	12
	10	11	12	13	15	8	9	11	13	18
S1B2	7	8	9	10	12	5	6	8	10	15
	10	11	12	13	15	8	8	9	9	11
	5	6	7	8	10	8	9	11	13	18
	5	6	8	10	15	10	11	12	13	15
	6	6	7	7	9	8	8	9	9	11
	5	6	7	8	10	7	8	9	10	12
S2B1	13	14	15	16	18	10	11	12	14	18
	12	12	13	13	15	12	13	14	16	20
	12	13	14	16	20	13	14	15	16	18
	10	12	14	17	23	10	12	14	17	23
	16	17	19	21	26	12	13	14	16	20
	16	17	19	21	26	14	16	19	22	29
S2B2	12	13	14	16	20	10	12	14	17	23
	16	17	19	21	26	13	14	15	16	18
	12	13	14	16	20	14	16	19	22	29
	10	12	14	17	23	16	17	19	21	26
	12	12	13	13	15	13	14	15	16	18
	12	13	14	16	20	12	13	14	16	20
S3B1	22	23	24	26	30	18	19	21	23	28
	20	21	22	23	25	20	22	24	27	33
	20	22	24	27	33	22	23	24	26	30
	17	20	23	28	37	17	20	23	28	37
	28	31	34	38	46	20	22	24	27	33
	28	31	34	38	46	23	28	33	39	52
S3B2	20	22	24	27	33	17	20	23	28	37
	28	31	34	38	46	22	23	24	26	30
	18	19	21	23	28	23	28	33	39	52
	17	20	23	28	37	28	31	34	38	46
	20	21	22	23	25	22	23	24	26	30
	18	19	21	23	28	20	22	24	27	33
S4B1	31	32	34	36	41	26	28	31	34	41
	29	30	31	33	37	28	31	34	38	46
	28	31	34	38	46	31	32	34	36	41
	23	28	33	39	52	23	28	33	39	52
	33	36	39	44	53	28	31	34	38	46
	33	36	39	44	53	28	34	39	45	59
S4B2	28	31	34	38	46	23	28	33	39	52
	33	36	39	44	53	31	32	34	36	41
	26	28	31	34	41	28	34	39	45	59
	23	28	33	39	52	33	36	39	44	53
	29	30	31	33	37	31	32	34	36	41
	26	28	31	34	41	28	31	34	38	46

EXPERIMENT #1—STANDARD DEVIATIONS *(continued)*

SCODE	SD1A	SD2A	SD3A	SD4A	SD5A	SD1B	SD2B	SD3B	SD4B	SD5B
S5B1	40	42	44	47	53	33	36	39	44	53
	37	38	40	42	47	36	39	43	48	59
	36	39	43	48	59	40	42	44	47	53
	30	36	42	50	66	30	36	42	50	66
	42	47	52	58	71	36	39	43	48	59
	42	47	52	58	71	37	44	51	60	78
S5B2	36	39	43	48	59	30	36	42	50	66
	42	47	52	58	71	40	42	44	47	53
	33	36	39	44	53	37	44	51	60	78
	30	36	42	50	66	42	47	52	58	71
	37	38	40	42	47	40	42	44	47	53
	33	36	39	44	53	36	39	43	48	59
S6B1	49	51	54	57	64	39	44	48	54	65
	45	47	49	52	58	43	48	53	59	72
	43	48	53	59	72	49	51	54	57	64
	37	44	52	61	81	37	44	52	61	81
	52	58	63	71	86	43	48	53	59	72
	52	58	63	71	86	44	53	62	74	98
S6B2	43	48	53	59	72	37	44	52	61	81
	52	58	63	71	86	49	51	54	57	64
	39	44	48	54	65	44	53	62	74	98
	37	44	52	61	81	52	58	63	71	86
	45	47	49	52	58	49	51	54	57	64
	39	44	48	54	65	43	48	53	59	72
S7B1	61	64	67	71	79	48	54	59	65	79
	55	57	60	63	70	53	59	65	73	89
	53	59	65	73	89	61	64	67	71	79
	46	55	64	76	100	46	55	64	76	100
	61	68	75	84	102	53	59	65	73	89
	61	68	75	84	102	54	64	73	86	113
S7B2	53	59	65	73	89	46	55	64	76	100
	61	68	75	84	102	61	64	67	71	79
	48	54	59	65	79	54	64	73	86	113
	46	55	64	76	100	61	68	75	84	102
	55	57	60	63	70	61	64	67	71	79
	48	54	59	65	79	53	59	65	73	89
S8B1	75	78	81	86	95	58	65	71	79	97
	67	70	73	77	85	65	72	80	89	109
	65	72	80	89	109	75	78	81	86	95
	57	67	78	92	121	57	67	78	92	121
	75	83	91	102	124	65	72	80	89	109
	75	83	91	102	124	64	77	89	106	139
S8B2	65	72	80	89	109	57	67	78	92	121
	75	83	91	102	124	75	78	81	86	95
	58	65	71	79	97	64	77	89	106	139
	57	67	78	92	121	75	83	91	102	124
	67	70	73	77	85	75	78	81	86	95
	58	65	71	79	97	65	72	80	89	109

EXPERIMENT #1—STANDARD DEVIATIONS ***(continued)***

SCODE	SD1A	SD2A	SD3A	SD4A	SD5A	SD1B	SD2B	SD3B	SD4B	SD5B
S9B1	98	103	108	114	127	77	86	95	107	131
	88	93	97	103	114	87	96	106	118	143
	87	96	106	118	143	98	103	108	114	127
	75	89	103	122	160	75	89	103	122	160
	101	111	122	136	165	87	96	106	118	143
	101	111	122	136	165	87	103	119	141	185
S9B2	87	96	106	118	143	75	89	103	122	160
	101	111	122	136	165	98	103	108	114	127
	77	86	95	107	131	87	103	119	141	185
	75	89	103	122	160	101	111	122	136	165
	88	93	97	103	114	98	103	108	114	127
	77	86	95	107	131	87	96	106	118	143

EXPERIMENT #1 TRAVEL TIME DISTRIBUTIONS

SCODE	DT1A	DT2A	DT3A	DT4A	DT5A	DT1B	DT2B	DT3B	DT4B	DT5B
S1B1	−10	−10	−9	−9	−7	−11	−10	−9	−8	−6
	−10	−10	−9	−9	−7	−11	−10	−9	−8	−6
	−11	−10	−9	−8	−6	−3	−3	−2	−2	0
	−6	−5	−3	−1	4	−4	−3	−1	1	6
	−4	−3	−2	−1	1	−2	−1	0	1	3
	−2	−1	0	1	3	−4	−3	−1	1	6
S1B2	−11	−10	−9	−8	−6	−6	−5	−3	−1	4
	−4	−3	−2	−1	1	−10	−10	−9	−9	−7
	−11	−10	−9	−8	−6	−4	−3	−1	1	6
	−4	−3	−1	1	6	−2	−1	0	1	3
	−10	−10	−9	−9	−7	−3	−3	−2	−2	0
	−4	−3	−2	−1	1	−2	−1	0	1	3
S2B1	−13	−12	−11	−10	−8	−14	−13	−12	−10	−6
	−12	−12	−11	−11	−9	−14	−13	−12	−10	−6
	−14	−13	−12	−10	−6	−4	−3	−2	−1	1
	−7	−5	−3	0	6	−5	−3	−1	2	8
	−6	−5	−3	−1	4	−3	−2	−1	1	5
	−4	−3	−1	1	6	−6	−4	−1	2	9
S2B2	−14	−13	−12	−10	−6	−7	−5	−3	0	6
	−6	−5	−3	−1	4	−13	−12	−11	−10	−8
	−12	−11	−10	−8	−4	−6	−4	−1	2	9
	−5	−3	−1	2	8	−4	−3	−1	1	6
	−12	−12	−11	−11	−9	−4	−3	−2	−1	1
	−3	−2	−1	1	5	−3	−2	−1	1	5
S3B1	−11	−10	−9	−7	−3	−12	−11	−9	−7	−2
	−10	−9	−8	−7	−5	−13	−11	−9	−6	0
	−13	−11	−9	−6	0	−6	−5	−4	−2	2
	−11	−8	−5	0	9	−8	−5	−2	3	12
	−10	−7	−4	0	8	−5	−3	−1	2	8
	−7	−4	−1	3	11	−12	−7	−2	4	17
S3B2	−13	−11	−9	−6	0	−11	−8	−5	0	9
	−10	−7	−4	0	8	−11	−10	−9	−7	−3
	−12	−11	−9	−7	−2	−12	−7	−2	4	17
	−8	−5	−2	3	12	−7	−4	−1	3	11
	−10	−9	−8	−7	−5	−6	−5	−4	−2	2
	−7	−6	−4	−2	3	−5	−3	−1	2	8
S4B1	−13	−12	−10	−8	−3	−15	−13	−10	−7	0
	−12	−11	−10	−8	−4	−16	−13	−10	−6	2
	−16	−13	−10	−6	2	−6	−5	−3	−1	4
	−14	−9	−4	2	15	−12	−7	−2	4	17
	−10	−7	−4	1	10	−7	−4	−1	3	11
	−8	−5	−2	3	12	−13	−7	−2	4	18
S4B2	−16	−13	−10	−6	2	−14	−9	−4	2	15
	−10	−7	−4	1	10	−13	−12	−10	−8	−3
	−15	−13	−10	−7	0	−13	−7	−2	4	18
	−12	−7	−2	4	17	−8	−5	−2	3	12
	−12	−11	−10	−8	−4	−6	−5	−3	−1	4
	−8	−6	−3	0	7	−7	−4	−1	3	11

EXPERIMENT #1 TRAVEL TIME DISTRIBUTIONS *(continued)*

SCODE	DT1A	DT2A	DT3A	DT4A	DT5A	DT1B	DT2B	DT3B	DT4B	DT5B
S5B1	−16	−14	−12	−9	−3	−19	−16	−13	−8	1
	−15	−14	−12	−10	−5	−20	−17	−13	−8	3
	−20	−17	−13	−8	3	−8	−6	−4	−1	5
	−18	−12	−6	2	18	−15	−9	−3	5	21
	−15	−10	−5	1	14	−9	−6	−2	3	14
	−12	−7	−2	4	17	−17	−10	−3	6	24
S5B2	−20	−17	−13	−8	3	−18	−12	−6	2	18
	−15	−10	−5	1	14	−16	−14	−12	−9	−3
	−19	−16	−13	−8	1	−17	−10	−3	6	24
	−15	−9	−3	5	21	−12	−7	−2	4	17
	−15	−14	−12	−10	−5	−8	−6	−4	−1	5
	−11	−8	−5	0	9	−9	−6	−2	3	14
S6B1	−20	−18	−15	−12	−5	−25	−20	−16	−10	1
	−19	−17	−15	−12	−6	−26	−21	−16	−10	3
	−26	−21	−16	−10	3	−10	−8	−5	−2	5
	−22	−15	−7	2	22	−18	−11	−3	6	26
	−18	−12	−7	1	16	−12	−7	−2	4	17
	−14	−8	−3	5	20	−22	−13	−4	8	32
S6B2	−26	−21	−16	−10	3	−22	−15	−7	2	22
	−18	−12	−7	1	16	−20	−18	−15	−12	−5
	−25	−20	−16	−10	1	−22	−13	−4	8	32
	−18	−11	−3	6	26	−14	−8	−3	5	20
	−19	−17	−15	−12	−6	−10	−8	−5	−2	5
	−15	−10	−6	0	11	−12	−7	−2	4	17
S7B1	−24	−21	−18	−14	−6	−30	−24	−19	−13	1
	−23	−21	−18	−15	−8	−32	−26	−20	−12	4
	−32	−26	−20	−12	4	−12	−9	−6	−2	6
	−27	−18	−9	3	27	−22	−13	−4	8	32
	−22	−15	−8	1	19	−15	−9	−3	5	21
	−17	−10	−3	6	24	−24	−14	−5	8	35
S7B2	−32	−26	−20	−12	4	−27	−18	−9	3	27
	−22	−15	−8	1	19	−24	−21	−18	−14	−6
	−30	−24	−19	−13	1	−24	−14	−5	8	35
	−22	−13	−4	8	32	−17	−10	−3	6	24
	−23	−21	−18	−15	−8	−12	−9	−6	−2	6
	−18	−12	−7	−1	13	−15	−9	−3	5	21
S8B1	−25	−22	−19	−14	−5	−33	−26	−20	−12	6
	−24	−21	−18	−14	−6	−35	−28	−20	−11	9
	−35	−28	−20	−11	9	−14	−11	−8	−3	6
	−32	−22	−11	3	32	−26	−16	−5	9	38
	−26	−18	−10	1	23	−18	−11	−3	6	26
	−20	−12	−4	7	29	−31	−18	−6	11	44
S8B2	−35	−28	−20	−11	9	−32	−22	−11	3	32
	−26	−18	−10	1	23	−25	−22	−19	−14	−5
	−33	−26	−20	−12	6	−31	−18	−6	11	44
	−26	−16	−5	9	38	−20	−12	−4	7	29
	−24	−21	−18	−14	−6	−14	−11	−8	−3	6
	−22	−15	−9	−1	17	−18	−11	−3	6	26

EXPERIMENT #1 TRAVEL TIME DISTRIBUTIONS *(continued)*

SCODE	DT1A	DT2A	DT3A	DT4A	DT5A	DT1B	DT2B	DT3B	DT4B	DT5B
S9B1	−29	−24	−19	−13	0	−39	−30	−21	−9	15
	−28	−23	−19	−13	−2	−40	−31	−21	−9	16
	−40	−31	−21	−9	16	−18	−13	−8	−2	11
	−41	−27	−13	6	44	−35	−21	−7	12	50
	−32	−22	−11	3	32	−23	−14	−4	8	33
	−26	−16	−5	9	38	−40	−24	−8	14	58
S9B2	−40	−31	−21	−9	16	−41	−27	−13	6	44
	−32	−22	−11	3	32	−29	−24	−19	−13	0
	−39	−30	−21	−9	15	−40	−24	−8	14	58
	−35	−21	−7	12	50	−26	−16	−5	9	38
	−28	−23	−19	−13	−2	−18	−13	−8	−2	11
	−28	−19	−10	2	26	−23	−14	−4	8	33

EXPERIMENT #2

SCODE	COST2A	TIME2A	PERC2A	CTIME2A	COST2B	TIME2B	PERC2B	CTIME2B
S1B1	0.25	8	75%	6	1.50	8	38%	3
	0.75	8	50%	4	0.25	9	56%	5
	0.25	9	56%	5	0.75	9	44%	4
	0.25	11	36%	4	1.50	8	38%	3
	0.75	9	44%	4	1.50	8	38%	3
	0.75	9	44%	4	0.25	11	36%	4
S1B2	0.25	9	78%	7	0.75	9	56%	5
	0.25	11	55%	6	1.50	9	44%	4
	0.75	9	56%	5	0.25	11	55%	6
	0.25	11	55%	6	1.50	8	50%	4
	0.75	9	56%	5	1.50	8	50%	4
	0.25	9	78%	7	1.50	8	50%	4
S2B1	0.75	13	77%	10	2.75	13	38%	5
	1.50	13	54%	7	0.75	15	53%	8
	0.75	15	53%	8	1.50	15	40%	6
	0.75	20	40%	8	2.75	13	38%	5
	1.50	15	40%	6	2.75	13	38%	5
	1.50	15	40%	6	0.75	20	40%	8
S2B2	0.75	15	80%	12	1.50	15	53%	8
	0.75	20	50%	10	2.75	15	40%	6
	1.50	15	53%	8	0.75	20	50%	10
	0.75	20	50%	10	2.75	13	54%	7
	1.50	15	53%	8	2.75	13	54%	7
	0.75	15	80%	12	2.75	13	54%	7
S3B1	1.25	23	78%	18	3.25	23	39%	9
	2.00	23	52%	12	1.25	25	52%	13
	1.25	25	52%	13	2.00	25	40%	10
	1.25	28	39%	11	3.25	23	39%	9
	2.00	25	40%	10	3.25	23	39%	9
	2.00	25	40%	10	1.25	28	39%	11
S3B2	1.25	25	80%	20	2.00	25	52%	13
	1.25	28	50%	14	3.25	25	40%	10
	2.00	25	52%	13	1.25	28	50%	14
	1.25	28	50%	14	3.25	23	52%	12
	2.00	25	52%	13	3.25	23	52%	12
	1.25	25	80%	20	3.25	23	52%	12
S4B1	2.00	32	81%	26	4.00	32	41%	13
	2.75	32	50%	16	2.00	35	51%	18
	2.00	35	51%	18	2.75	35	40%	14
	2.00	40	40%	16	4.00	32	41%	13
	2.75	35	40%	14	4.00	32	41%	13
	2.75	35	40%	14	2.00	40	40%	16
S4B2	2.00	35	80%	28	2.75	35	51%	18
	2.00	40	50%	20	4.00	35	40%	14
	2.75	35	51%	18	2.00	40	50%	20
	2.00	40	50%	20	4.00	32	50%	16
	2.75	35	51%	18	4.00	32	50%	16
	2.00	35	80%	28	4.00	32	50%	16

EXPERIMENT #2 ***(continued)***

SCODE	COST2A	TIME2A	PERC2A	CTIME2A	COST2B	TIME2B	PERC2B	CTIME2B
S5B1	2.75	41	80%	33	4.75	41	39%	16
	3.50	41	51%	21	2.75	45	51%	23
	2.75	45	51%	23	3.50	45	40%	18
	2.75	51	39%	20	4.75	41	39%	16
	3.50	45	40%	18	4.75	41	39%	16
	3.50	45	40%	18	2.75	51	39%	20
S5B2	2.75	45	80%	36	3.50	45	51%	23
	2.75	51	51%	26	4.75	45	40%	18
	3.50	45	51%	23	2.75	51	51%	26
	2.75	51	51%	26	4.75	41	51%	21
	3.50	45	51%	23	4.75	41	51%	21
	2.75	45	80%	36	4.75	41	51%	21
S6B1	3.25	50	80%	40	6.00	50	40%	20
	4.25	50	50%	25	3.25	55	51%	28
	3.25	55	51%	28	4.25	55	40%	22
	3.25	63	40%	25	6.00	50	40%	20
	4.25	55	40%	22	6.00	50	40%	20
	4.25	55	40%	22	3.25	63	40%	25
S6B2	3.25	55	80%	44	4.25	55	51%	28
	3.25	63	51%	32	6.00	55	40%	22
	4.25	55	51%	28	3.25	63	51%	32
	3.25	63	51%	32	6.00	50	50%	25
	4.25	55	51%	28	6.00	50	50%	25
	3.25	55	80%	44	6.00	50	50%	25
S7B1	4.25	64	70%	45	7.25	64	41%	26
	5.00	64	50%	32	4.25	68	50%	34
	4.25	68	50%	34	5.00	68	40%	27
	4.25	78	40%	31	7.25	64	41%	26
	5.00	68	40%	27	7.25	64	41%	26
	5.00	68	40%	27	4.25	78	40%	31
S7B2	4.25	68	71%	48	5.00	68	50%	34
	4.25	78	50%	39	7.25	68	40%	27
	5.00	68	50%	34	4.25	78	50%	39
	4.25	78	50%	39	7.25	64	50%	32
	5.00	68	50%	34	7.25	64	50%	32
	4.25	68	71%	48	7.25	64	50%	32
S8B1	5.00	78	71%	55	8.00	78	40%	31
	5.75	78	50%	39	5.00	83	51%	42
	5.00	83	51%	42	5.75	83	40%	33
	5.00	95	40%	38	8.00	78	40%	31
	5.75	83	40%	33	8.00	78	40%	31
	5.75	83	40%	33	5.00	95	40%	38
S8B2	5.00	83	70%	58	5.75	83	51%	42
	5.00	95	51%	48	8.00	83	40%	33
	5.75	83	51%	42	5.00	95	51%	48
	5.00	95	51%	48	8.00	78	50%	39
	5.75	83	51%	42	8.00	78	50%	39
	5.00	83	70%	58	8.00	78	50%	39

EXPERIMENT #2 *(continued)*

SCODE	COST2A	TIME2A	PERC2A	CTIME2A	COST2B	TIME2B	PERC2B	CTIME2B
S9B1	7.00	104	65%	68	10.00	104	40%	42
	8.00	104	50%	52	7.00	110	50%	55
	7.00	110	50%	55	8.00	110	40%	44
	7.00	124	40%	50	10.00	104	40%	42
	8.00	110	40%	44	10.00	104	40%	42
	8.00	110	40%	44	7.00	124	40%	50
S9B2	7.00	110	65%	72	8.00	110	50%	55
	7.00	124	50%	62	10.00	110	40%	44
	8.00	110	50%	55	7.00	124	50%	62
	7.00	124	50%	62	10.00	104	50%	52
	8.00	110	50%	55	10.00	104	50%	52
	7.00	110	65%	72	10.00	104	50%	52

APPENDIX D

PRELIMINARY TEST OF PASSENGER STATED PREFERENCE QUESTIONS

A pre-test of possible stated preference questions was conducted using an undergraduate economics class at UC Irvine. The purpose was to test the question formats for their relative difficulty and to try to identify any political biases against travel costs in the survey questions. The research team found no detectable political biases in the answers but did find that one of the survey formats was relatively more difficult for respondents to understand.

The research team obtained 67 usable surveys from the pre-test. These surveys were divided into three groups testing three different formats for one of the stated preference experiments. In addition, the research team included various questions on environmental attitudes and attitudes toward toll roads and road pricing. Some of the questions were designed so that it was fairly obvious to respondents that they should select the higher cost choice (i.e., the benefits of lower travel time or variance in the higher cost choice were quite substantial). The research team also asked about whether the survey was difficult to answer.

POLITICAL BIAS

The debate over toll roads in Southern California has been fueled by two groups. The environmental movement has opposed the construction of toll roads primarily because toll roads open new land to development. Others oppose the concept of toll roads because they feel that roads should remain free.

Previous survey work in Southern California found a bias against using the word "toll" in similar stated preference questions. Almost all respondents were found to select the cheaper alternative without regard to the relative benefits of the other option (see Small et al., 1995). The stated preference questions for this research have been designed to eliminate the use of the word "toll." Instead, the research team uses "your cost" and relates this to "include vehicle operating costs, gasoline, parking, and any other miscellaneous costs associated with the trip." This wording seems to have eliminated biased responses in the stated preference pre-test.

Specific stated preference questions were designed to have most people select the higher cost choice. For example, one question has a difference of 15 minutes in the average travel times. Cross-tabulations of the answers to these questions were analyzed according to whether respondents indicated their concern for the environment and also whether they were opposed to toll roads of any sort. In all cases, there was no statistical difference (using chi-square test) in the percent choosing the lower cost option between those indicating either a concern for the environment or no concern and for those indicating opposition to tolls and those who do not. In fact, for all four of these questions, most respondents chose the higher cost option, indicating that they are willing to pay for travel time advantages despite their political beliefs.

Two additional questions were designed to provide actual choices. These received a good split with between 40 to 60 percent choosing either option. Again, there was no significant difference in how either those concerned with the environment or those opposed to toll roads answered these questions.

These results indicate that the wording of the questions has eliminated any major political biases in responses.

QUESTION DIFFICULTY

The pre-test also attempted to measure the relative difficulty of the questions as perceived by the respondents. The research team included a yes/no question about whether or not the questions were "difficult to understand and answer." The results indicate that one of the formats was significantly more difficult than the other two formats.

Each questionnaire contained two stated preference formats. Every respondent received the question dealing with congested travel time, while the question dealing with reliability was given in one of three formats, shown below.

Format 1 is essentially the same as the stated preference question used in Small et al. (1995), but including a cost attribute, and similar to that of Black and Towriss (1993), which did not include the departure time. The questionnaires with this format were rated as being difficult by 60 percent of those answering it. This compares with 26.7 percent and 27.3 percent for Formats 2 and 3, respectively.

FORMAT 1

Total Travel Time: minutes				
16	18	20	22	24

Depart 20 minutes before your desired arrival time

your cost: $2.00

FORMAT 2

Average Travel Time: 20 minutes

Probability of arriving late: 40%

Average Minutes Late: 3 minutes

Average Minutes Early: 4 minutes

your cost: $2.00

FORMAT 3

Average Travel Time: 20 minutes

Probability of arriving late: 40%

On average you will arrive 2 minutes late

your cost: $2.00

Formats 2 and 3 were equivalent representations of the stated preference questions in Format 1. With one exception, respondents answered these questions with the same percent breakdowns. The one exception indicated another problem with Format 1 that suggested that people were not processing the mean travel time correctly. Question 3 in the pre-test had the following format with the rather obvious answer that one should choose the higher cost choice B, given the large 10-min difference in mean travel times.

QUESTION 3, FORMAT 1

Choice A	Choice B
Total Travel Time: minutes 26 28 30 32 34	Total Travel Time: minutes 16 18 20 22 24
Depart 30 minutes before your desired arrival time	Depart 20 minutes before your desired arrival time
your cost: $2.00	your cost: $2.50

When this question was presented as Format 2 or 3, the research team found 86.7 percent and 63.6 percent chose B. When presented as Format 1, the research team found only 26.7 percent chose B. This suggested that the research team needed to state more precisely what the average travel time is.

MODIFICATIONS TO STATED PREFERENCE SURVEY

Format 2 has the advantage of explicitly stating the values of the attributes in the expected cost equation, with the exception of the standard deviation. However, Format 2 has the disadvantage of presenting five attributes. Discussions with experts at the MVA Consultancy indicated that recommended practice for stated preference surveys is to present no more than four attributes—five attributes is the absolute maximum feasible. Format 3 does not provide enough information for analysis. The expected schedule delays (early and late) are lumped together in this format; this would not allow the research team to calculate separate coefficient values for these attributes. The only advantage is that it is somewhat simpler for respondents to interpret, but the research team believes the loss of information is not worth this advantage.

For these reasons, the research team used Format 1, but modified it as follows:

MODIFIED FORMAT 1

Average Travel Time: 20 minutes

You have an equal chance of arriving at any of the following times:

4 minutes early	2 minutes early	on time	2 minutes late	4 minutes late

your cost: $2.00

This modification eliminates the need for respondents to interpret the departure time relative to the distribution of travel times, while maintaining all the original information in the original version of Format 1.[1] It also highlights the average travel time which the pre-test results suggest may be important. Ultimately, this question was rearranged into the format shown in Section 3.2.

[1] The research team would like to thank members of the NCHRP review committee for suggesting this modification.

APPENDIX E

SURVEY COVER LETTERS AND POSTCARDS

INITIAL COVER LETTER SENT WITH PRE-SURVEY

Dear _______ :

Residents of Southern California experience some of the worst traffic congestion in the nation. Despite continued construction of freeways and mass transit systems, these problems seem to be getting worse. Understanding the travel behavior of people is crucial to solving these problems.

Your name has been drawn at random from residents of Orange and Riverside Counties. Your answers are important to determine how we can improve transportation and the living environment in Southern California. To truly represent the travel behavior of Southern California residents, it is important that each questionnaire be completed and returned. We would like the questionnaire for your household to be completed by an adult female. If none is present, then it should be completed by an adult male. As a small incentive, those who complete both this questionnaire and our short follow-up questionnaire (to be mailed a few days after we receive the first questionnaire) will be entered into a random drawing for a cash prize of $400.00.

You may be assured of complete confidentiality. The questionnaire has an identification number for mailing purposes only. This is so that we may check your name off the mailing list when your questionnaire is returned and enter you in our prize drawing. Your name will never be placed on the questionnaire, or be given to any other person or organization.

The results of this research will be made available to transportation planners and representatives of state and local governments, and all interested citizens. You may receive a summary of results by writing "copy of results requested" on the back of the return envelope and printing your name and address below it. Please do not put this information on the questionnaire itself.

This research is being conducted by the Institute of Transportation Studies at the University of California, Irvine. I would be most happy to answer any questions you might have. Please write or call. The telephone number is (714) 824-2887.

Thank you for your assistance.

Sincerely,

Robert B. Noland
Project Director

FIRST FOLLOW-UP POST CARD SENT ONE WEEK AFTER INITIAL MAILING

Last week a questionnaire about transportation in Southern California was mailed to you. Your name was randomly drawn from residents of Orange and Riverside counties.

If you have already completed and returned it to us please accept our sincere thanks. You may have already received the short follow-up questionnaire. If you have not yet sent back the first questionnaire, please do so today. Because it has only been sent to a small, but representative, sample of Southern California residents it is extremely important that yours be included in the study to accurately understand travel behavior in Southern California. As you may recall, we are also entering the names of those who have returned both questionnaires into a drawing for a cash prize of $400.00.

If by some chance you did not receive the questionnaire, or it got misplaced, please call me right now at (714) 824-2887 and I will get another one in the mail to you today.

Sincerely, Robert B. Noland,

Project Director

SECOND FOLLOW-UP LETTER SENT THREE WEEKS AFTER INITIAL MAILING

Dear ______ :

About three weeks ago you were sent a survey about transportation in Orange and Riverside Counties. As of today we have not yet received your completed questionnaire.

We have undertaken this study to seek solutions to worsening traffic congestion in Southern California. Your answers to our questionnaire are very important for us to find successful solutions to these problems. Please return the questionnaire *even if you are not currently employed or if you do not drive on the freeway.* Your name was randomly drawn from residents of Orange and Riverside Counties. In order for the results of this study to be truly representative of these two counties it is essential that each person in the sample return their questionnaire. We would like the questionnaire for your household to be completed by an <u>adult female</u>. If none is present, then it should be completed by an adult male.

In the event that your questionnaire has been misplaced, a replacement is enclosed. You may recall that we are offering an incentive to those who complete both this questionnaire and a short follow-up questionnaire (to be mailed a few days after we receive the first questionnaire). After we receive both, your name will be entered into a random drawing for a cash prize of $400.00.

You may be assured of complete confidentiality. The questionnaire has an identification number for mailing purposes only. This is so that we may check your name off the mailing list when your questionnaire is returned and enter you in our prize drawing. Your name will never be placed on the questionnaire, or be given to any other person or organization.

This research is being conducted by the Institute of Transportation Studies at the University of California, Irvine. I would be most happy to answer any questions you might have. Please write or call. The telephone number is (714) 824-2887. Thank you for your assistance.

Sincerely,

Robert B. Noland
Project Director

COVER LETTER SENT WITH STATED PREFERENCE PASSENGER SURVEY

Dear ______ :

Thank you for returning the survey on transportation we sent to you. We have used your answers on the first survey to prepare a short follow-up customized for your specific travel on a day-to-day basis. For this reason, please be sure that the <u>same household member</u> who answered the first survey fills out this brief follow-up questionnaire.

Given the small number of households selected to answer this survey, it is very important that you answer and return the questionnaire. Your answers will be very important for understanding how we can improve transportation in Southern California.

After we receive this final questionnaire, your name will be placed in a random drawing for a cash prize of $400.00. We expect to make the drawing in early October.

You may be assured of complete confidentiality. The questionnaire has an identification number for mailing purposes only. This is so that we may check your name off the mailing list when your questionnaire is returned and enter you in our prize drawing. Your name will never be placed on the questionnaire, or be given to any other person or organization.

If you have any questions please do not hesitate to call. My telephone number is (714) 824-2887.

Thank you for your assistance.

Sincerely,

Robert B. Noland
Project Director

FOLLOW-UP POST CARD SENT ONE WEEK AFTER STATED PREFERENCE SURVEY MAILED

Last week we sent you a customized questionnaire about transportation in Southern California. If you have already completed and returned it to us please accept our sincere thanks. If you have not yet sent back the questionnaire, please do so today. Because it has only been sent to a small, but representative, sample of Southern California residents it is extremely important that yours be included in the study to accurately understand travel behavior in Southern California. As you may recall, we are also entering the names of those who return this final questionnaire into a drawing for a cash prize of $400.00.

If by some chance you did not receive the second follow-up questionnaire, or it got misplaced, please call me right now at (714) 824-2887 and I will get another one in the mail to you today.

Sincerely, Robert B. Noland,

Project Director

FOLLOW-UP LETTER SENT THREE WEEKS AFTER STATED PREFERENCE SURVEY MAILED

Dear _______:

About three weeks ago you were sent a customized survey about transportation in Orange and Riverside Counties. As of today we have not yet received your completed questionnaire.

We have undertaken this study to seek solutions to worsening traffic congestion in Southern California. Your answers to our questionnaire are very important for us to find successful solutions to these problems. Your name was randomly drawn from residents of Orange and Riverside Counties. In order for the results of this study to be truly representative of these two counties it is essential that each person in the sample return their questionnaire.

Since this second questionnaire has been individually customized according to the answers we received on the first survey, it should be completed by the <u>same household member</u> who filled out the first questionnaire.

In the event that your questionnaire has been misplaced, a replacement is enclosed. You may recall that we are offering an incentive to those who complete this final questionnaire. Your name will be entered into a random drawing for a cash prize of $400.00 (to be drawn in late September).

This research is being conducted by the Institute of Transportation Studies at the University of California, Irvine. I would be most happy to answer any questions you might have. Please write or call. The telephone number is (714) 824-2887.

Thank you for your assistance.

Sincerely,

Robert B. Noland
Project Director

APPENDIX F

FREIGHT SURVEY STATED PREFERENCE DATA

The following table presents the stated preference survey data used in the analysis. The first column indexes the 120 experiments from the final sample 20 carrier firms. The second column shows the two alternatives for any given experiment, with 1 indicating the chosen alternative. The other columns give the values of C, T, CV, S, P_L, SDE, and SDL, respectively, for both alternatives in any given experiment. The values for C and T appeared in the stated preference experiments. The values for the other variables were calculated with information from the stated preference experiments.

TABLE F1 Stated Preference Survey Data

Exper.	Choice	C	T	CV	SD	P_L	SDE	SDL
1	0	250	2.5	0.1	0.2500	0.2	0.2682	0.0154
	1	250	1.9	0.2	0.3810	0.0	0.8590	0.0000
2	0	310	1.9	0.1	0.1905	0.0	0.8522	0.0000
	1	190	2.5	0.2	0.5000	0.4	0.4316	0.1562
3	1	190	2.5	0.2	0.5000	0.2	0.3434	0.0820
	0	310	2.5	0.1	0.2500	0.2	0.1682	0.0404
4	1	190	2.5	0.3	0.7500	0.4	0.3566	0.2062
	0	250	2.5	0.3	0.7500	0.8	0.0284	0.6140
5	0	190	3.1	0.2	0.6190	0.8	0.0534	0.5140
	1	310	2.5	0.2	0.5000	0.4	0.2816	0.2562
6	0	250	3.1	0.2	0.6190	0.8	0.0284	0.6140
	1	190	3.1	0.3	0.9286	0.8	0.0924	0.6606
7	1	30	0.5	0.2	0.1000	0.2	0.0688	0.0164
	0	30	0.5	0.3	0.1500	0.4	0.0712	0.0414
8	1	30	0.6	0.2	0.1250	0.8	0.0138	0.0858
	0	50	0.5	0.1	0.0500	0.2	0.0536	0.0030
9	1	50	0.4	0.2	0.0750	0.0	0.1518	0.0000
	0	30	0.6	0.3	0.1875	0.6	0.0224	0.1164
10	1	50	0.5	0.3	0.1500	0.4	0.0562	0.0514
	0	50	0.6	0.2	0.1250	0.8	0.0088	0.1058
11	1	60	0.4	0.1	0.0375	0.0	0.1506	0.0000
	0	60	0.5	0.1	0.0500	0.2	0.0336	0.0080
12	1	60	0.4	0.2	0.0750	0.0	0.1268	0.0000
	0	60	0.5	0.2	0.1000	0.4	0.0376	0.0352
13	0	860	7.5	0.1	0.7500	0.2	0.8050	0.0460
	1	860	5.9	0.2	1.1809	0.0	2.3770	0.0000
14	0	1070	5.9	0.1	0.5904	0.0	2.3628	0.0000
	1	640	7.5	0.2	1.5000	0.2	1.0304	0.2458
15	1	640	7.5	0.2	1.5000	0.2	1.0304	0.2458
	0	1070	7.5	0.1	0.7500	0.2	0.5050	0.1210
16	1	640	7.5	0.3	2.2500	0.4	1.0702	0.6188
	0	860	7.5	0.3	2.2500	0.4	0.8452	0.7688
17	0	640	9.1	0.2	1.8191	0.8	0.1904	1.3734
	1	1070	7.5	0.2	1.5000	0.4	0.5622	0.5276
18	0	860	9.1	0.2	1.8191	0.8	0.1154	1.6734
	1	640	9.1	0.3	2.7287	0.6	0.3088	1.8160
19	0	140	1.5	0.1	0.1500	0.2	0.1610	0.0092
	1	140	1.1	0.2	0.2268	0.0	0.5550	0.0000
20	0	180	1.1	0.1	0.1134	0.0	0.5512	0.0000
	1	110	1.5	0.2	0.3000	0.2	0.2060	0.0492
21	1	110	1.5	0.2	0.3000	0.2	0.2060	0.0492
	0	180	1.5	0.1	0.1500	0.2	0.1010	0.0242

TABLE F1 ***(continued)***

Exper.	Choice	*C*	*T*	*CV*	*SD*	P_L	*SDE*	*SDL*
22	1	110	1.5	0.3	0.4500	0.4	0.2140	0.1238
	0	140	1.5	0.3	0.4500	0.4	0.1690	0.1538
23	1	110	1.9	0.2	0.3732	0.8	0.0260	0.3420
	0	180	1.5	0.2	0.3000	0.4	0.1124	0.1056
24	0	140	1.9	0.2	0.3732	0.8	0.0110	0.4020
	1	110	1.9	0.3	0.5598	0.8	0.0502	0.4308
25	1	450	5.5	0.2	1.1000	0.4	0.9500	0.3438
	0	450	5.5	0.3	1.6500	0.4	0.7850	0.4538
26	0	450	6.7	0.2	1.3444	0.8	0.1356	1.0298
	1	590	5.5	0.1	0.5500	0.2	0.5900	0.0338
27	1	590	4.3	0.2	0.8556	0.0	1.7698	0.0000
	0	450	6.7	0.3	2.0167	0.8	0.2190	1.3506
28	1	590	5.5	0.3	1.6500	0.4	0.6200	0.5638
	0	590	6.7	0.2	1.3444	0.8	0.0806	1.2498
29	1	740	4.3	0.1	0.4278	0.0	1.7550	0.0000
	0	740	5.5	0.1	0.5500	0.2	0.3700	0.0888
30	1	740	4.3	0.2	0.8556	0.0	1.4948	0.0000
	0	740	5.5	0.2	1.1000	0.4	0.6200	0.5638
31	1	190	2.5	0.2	0.5000	0.4	0.4316	0.1562
	0	190	2.5	0.3	0.7500	0.8	0.0534	0.5140
32	0	190	3.1	0.2	0.6190	0.8	0.0534	0.5140
	1	250	2.5	0.1	0.2500	0.2	0.2682	0.0154
33	1	250	1.9	0.2	0.3810	0.0	0.8590	0.0000
	0	190	3.1	0.3	0.9286	0.8	0.0924	0.6606
34	0	250	2.5	0.3	0.7500	0.8	0.0284	0.6140
	1	250	3.1	0.2	0.6190	0.8	0.0284	0.6140
35	1	310	1.9	0.1	0.1905	0.0	0.8522	0.0000
	0	310	2.5	0.1	0.2500	0.2	0.1682	0.0404
36	1	310	1.9	0.2	0.3810	0.0	0.7340	0.0000
	0	310	2.5	0.2	0.5000	0.4	0.2816	0.2562
37	1	140	1.5	0.1	0.1500	0.2	0.1610	0.0092
	0	140	1.1	0.2	0.2268	0.0	0.5550	0.0000
38	0	180	1.1	0.1	0.1134	0.0	0.5512	0.0000
	1	110	1.5	0.2	0.3000	0.2	0.2060	0.0492
39	1	110	1.5	0.2	0.3000	0.2	0.2060	0.0492
	0	180	1.5	0.1	0.1500	0.2	0.1010	0.0242
40	1	110	1.5	0.3	0.4500	0.4	0.2140	0.1238
	0	140	1.5	0.3	0.4500	0.4	0.1690	0.1538
41	0	110	1.9	0.2	0.3732	0.8	0.0260	0.3420
	1	180	1.5	0.2	0.3000	0.4	0.1124	0.1056
42	1	140	1.9	0.2	0.3732	0.8	0.0110	0.4020
	0	110	1.9	0.3	0.5598	0.8	0.0502	0.4308

TABLE F1 ***(continued)***

Exper.	Choice	C	T	CV	SD	P_L	SDE	SDL
43	1	110	1.5	0.2	0.3000	0.2	0.2060	0.0492
	0	110	1.5	0.3	0.4500	0.4	0.2140	0.1238
44	1	110	1.9	0.2	0.3732	0.8	0.0260	0.3420
	0	140	1.5	0.1	0.1500	0.2	0.1610	0.0092
45	0	140	1.1	0.2	0.2268	0.0	0.5550	0.0000
	1	110	1.9	0.3	0.5598	0.8	0.0502	0.4308
46	1	140	1.5	0.3	0.4500	0.4	0.1690	0.1538
	0	140	1.9	0.2	0.3732	0.8	0.0110	0.4020
47	1	180	1.1	0.1	0.1134	0.0	0.5512	0.0000
	0	180	1.5	0.1	0.1500	0.2	0.1010	0.0242
48	0	180	1.1	0.2	0.2268	0.0	0.4800	0.0000
	1	180	1.5	0.2	0.3000	0.4	0.1124	0.1056
49	1	190	2.5	0.2	0.5000	0.4	0.4316	0.1562
	0	190	2.5	0.3	0.7500	0.8	0.0534	0.5140
50	0	190	3.1	0.2	0.6190	0.8	0.0534	0.5140
	1	250	2.5	0.1	0.2500	0.2	0.2682	0.0154
51	0	250	1.9	0.2	0.3810	0.0	0.8590	0.0000
	1	190	3.1	0.3	0.9286	0.8	0.0924	0.6606
52	1	250	2.5	0.3	0.7500	0.8	0.0284	0.6140
	0	250	3.1	0.2	0.6190	0.8	0.0284	0.6140
53	0	310	1.9	0.1	0.1905	0.0	0.8522	0.0000
	1	310	2.5	0.1	0.2500	0.2	0.1682	0.0404
54	0	310	1.9	0.2	0.3810	0.0	0.7340	0.0000
	1	310	2.5	0.2	0.5000	0.4	0.2816	0.2562
55	0	250	2.5	0.1	0.2500	0.2	0.2682	0.0154
	1	250	1.9	0.2	0.3810	0.0	0.8590	0.0000
56	0	310	1.9	0.1	0.1905	0.0	0.8522	0.0000
	1	190	2.5	0.2	0.5000	0.4	0.4316	0.1562
57	1	190	2.5	0.2	0.5000	0.2	0.3434	0.0820
	0	310	2.5	0.1	0.2500	0.2	0.1682	0.0404
58	1	190	2.5	0.3	0.7500	0.4	0.3566	0.2062
	0	250	2.5	0.3	0.7500	0.8	0.0284	0.6140
59	0	190	3.1	0.2	0.6190	0.8	0.0534	0.5140
	1	310	2.5	0.2	0.5000	0.4	0.2816	0.2562
60	1	250	3.1	0.2	0.6190	0.8	0.0284	0.6140
	0	190	3.1	0.3	0.9286	0.8	0.0924	0.6606
61	0	860	7.5	0.1	0.7500	0.2	0.8050	0.0460
	1	860	5.9	0.2	1.1809	0.0	2.3770	0.0000
62	0	1070	5.9	0.1	0.5904	0.0	2.3628	0.0000
	1	640	7.5	0.2	1.5000	0.2	1.0304	0.2458
63	1	640	7.5	0.2	1.5000	0.2	1.0304	0.2458
	0	1070	7.5	0.1	0.7500	0.2	0.5050	0.1210

TABLE F1 ***(continued)***

Exper.	Choice	*C*	*T*	*CV*	*SD*	P_L	*SDE*	*SDL*
64	1	640	7.5	0.3	2.2500	0.4	1.0702	0.6188
	0	860	7.5	0.3	2.2500	0.4	0.8452	0.7688
65	0	640	9.1	0.2	1.8191	0.8	0.1904	1.3734
	1	1070	7.5	0.2	1.5000	0.4	0.5622	0.5276
66	0	860	9.1	0.2	1.8191	0.8	0.1154	1.6734
	1	640	9.1	0.3	2.7287	0.6	0.3088	1.8160
67	0	360	3.5	0.1	0.3500	0.2	0.3754	0.0216
	1	360	2.7	0.2	0.5372	0.0	1.1626	0.0000
68	0	450	2.7	0.1	0.2686	0.0	1.1530	0.0000
	1	270	3.5	0.2	0.7000	0.2	0.4808	0.1148
69	1	270	3.5	0.2	0.7000	0.2	0.4808	0.1148
	0	450	3.5	0.1	0.3500	0.2	0.2354	0.0566
70	1	270	3.5	0.3	1.0500	0.4	0.4996	0.2888
	0	360	3.5	0.3	1.0500	0.4	0.3946	0.3588
71	1	270	4.3	0.2	0.8628	0.8	0.0808	0.6860
	0	450	3.5	0.2	0.7000	0.4	0.2624	0.2464
72	0	360	4.3	0.2	0.8628	0.8	0.0458	0.8260
	1	270	4.3	0.3	1.2942	0.8	0.1346	0.7380
73	1	350	4.5	0.2	0.9000	0.2	0.6180	0.1456
	0	350	4.5	0.3	1.3500	0.4	0.6422	0.3714
74	0	350	5.5	0.2	1.1045	0.8	0.1082	0.8576
	1	470	4.5	0.1	0.4500	0.2	0.4830	0.0276
75	1	470	3.5	0.2	0.6955	0.0	1.4660	0.0000
	0	350	5.5	0.3	1.6568	0.8	0.1768	1.1206
76	1	470	4.5	0.3	1.3500	0.4	0.5072	0.4614
	0	470	5.5	0.2	1.1045	0.8	0.0632	1.0376
77	1	590	3.5	0.1	0.3477	0.0	1.4538	0.0000
	0	590	4.5	0.1	0.4500	0.2	0.3030	0.0726
78	1	590	3.5	0.2	0.6955	0.0	1.2410	0.0000
	0	590	4.5	0.2	0.9000	0.4	0.3372	0.3148
79	1	30	0.5	0.2	0.1000	0.2	0.0688	0.0164
	0	30	0.5	0.3	0.1500	0.4	0.0712	0.0414
80	1	30	0.6	0.2	0.1250	0.8	0.0138	0.0858
	0	50	0.5	0.1	0.0500	0.2	0.0536	0.0030
81	0	50	0.4	0.2	0.0750	0.0	0.1518	0.0000
	1	30	0.6	0.3	0.1875	0.6	0.0224	0.1164
82	0	50	0.5	0.3	0.1500	0.4	0.0562	0.0514
	1	50	0.6	0.2	0.1250	0.8	0.0088	0.1058
83	0	60	0.4	0.1	0.0375	0.0	0.1506	0.0000
	1	60	0.5	0.1	0.0500	0.2	0.0336	0.0080
84	0	60	0.4	0.2	0.0750	0.0	0.1268	0.0000
	1	60	0.5	0.2	0.1000	0.4	0.0376	0.0352

TABLE F1 ***(continued)***

Exper.	Choice	C	T	CV	SD	P_L	SDE	SDL
85	1	190	2.5	0.2	0.5000	0.4	0.4316	0.1562
	0	190	2.5	0.3	0.7500	0.8	0.0534	0.5140
86	0	190	3.1	0.2	0.6190	0.8	0.0534	0.5140
	1	250	2.5	0.1	0.2500	0.2	0.2682	0.0154
87	1	250	1.9	0.2	0.3810	0.0	0.8590	0.0000
	0	190	3.1	0.3	0.9286	0.8	0.0924	0.6606
88	1	250	2.5	0.3	0.7500	0.8	0.0284	0.6140
	0	250	3.1	0.2	0.6190	0.8	0.0284	0.6140
89	1	310	1.9	0.1	0.1905	0.0	0.8522	0.0000
	0	310	2.5	0.1	0.2500	0.2	0.1682	0.0404
90	1	310	1.9	0.2	0.3810	0.0	0.7340	0.0000
	0	310	2.5	0.2	0.5000	0.4	0.2816	0.2562
91	1	30	0.5	0.2	0.1000	0.2	0.0688	0.016
	0	30	0.5	0.3	0.1500	0.4	0.0712	0.0414
92	0	30	0.6	0.2	0.1250	0.8	0.0138	0.0858
	1	50	0.5	0.1	0.0500	0.2	0.0536	0.0030
93	1	50	0.4	0.2	0.0750	0.0	0.1518	0.0000
	0	30	0.6	0.3	0.1875	0.6	0.0224	0.1164
94	1	50	0.5	0.3	0.1500	0.4	0.0562	0.0514
	0	50	0.6	0.2	0.1250	0.8	0.0088	0.1058
95	1	60	0.4	0.1	0.0375	0.0	0.1506	0.0000
	0	60	0.5	0.1	0.0500	0.2	0.0336	0.0080
96	1	60	0.4	0.2	0.0750	0.0	0.1268	0.0000
	0	60	0.5	0.2	0.1000	0.4	0.0376	0.0352
97	0	50	0.5	0.1	0.0500	0.2	0.0536	0.0030
	1	50	0.4	0.2	0.0750	0.0	0.1518	0.0000
98	0	60	0.4	0.1	0.0375	0.0	0.1506	0.0000
	1	30	0.5	0.2	0.1000	0.2	0.0688	0.0164
99	1	30	0.5	0.2	0.1000	0.2	0.0688	0.0164
	0	60	0.5	0.1	0.0500	0.2	0.0336	0.0080
100	1	30	0.5	0.3	0.1500	0.4	0.0712	0.0414
	0	50	0.5	0.3	0.1500	0.4	0.0562	0.0514
101	0	30	0.6	0.2	0.1250	0.8	0.0138	0.0858
	1	60	0.5	0.2	0.1000	0.4	0.0376	0.0352
102	0	50	0.6	0.2	0.1250	0.8	0.0088	0.1058
	1	30	0.6	0.3	0.1875	0.6	0.0224	0.1164
103	1	470	4.5	0.1	0.4500	0.2	0.4830	0.0276
	0	470	3.5	0.2	0.6955	0.0	1.4660	0.0000
104	0	590	3.5	0.1	0.3477	0.0	1.4538	0.0000
	1	350	4.5	0.2	0.9000	0.2	0.6180	0.1456
105	1	350	4.5	0.2	0.9000	0.2	0.6180	0.1456
	0	590	4.5	0.1	0.4500	0.2	0.3030	0.0726

TABLE F1 *(continued)*

Exper.	Choice	C	T	CV	SD	P_L	SDE	SDL
106	1	350	4.5	0.3	1.3500	0.4	0.6422	0.3714
	0	470	4.5	0.3	1.3500	0.4	0.5072	0.4614
107	1	350	5.5	0.2	1.1045	0.8	0.1082	0.8576
	0	590	4.5	0.2	0.9000	0.4	0.3372	0.3148
108	0	470	5.5	0.2	1.1045	0.8	0.0632	1.0376
	1	350	5.5	0.3	1.6568	0.8	0.1768	1.1206
109	1	140	1.5	0.1	0.1500	0.2	0.1610	0.0092
	0	140	1.1	0.2	0.2268	0.0	0.5550	0.0000
110	0	180	1.1	0.1	0.1134	0.0	0.5512	0.0000
	1	110	1.5	0.2	0.3000	0.2	0.2060	0.0492
111	1	110	1.5	0.2	0.3000	0.2	0.2060	0.0492
	0	180	1.5	0.1	0.1500	0.2	0.1010	0.0242
112	1	110	1.5	0.3	0.4500	0.4	0.2140	0.1238
	0	140	1.5	0.3	0.4500	0.4	0.1690	0.1538
113	0	110	1.9	0.2	0.3732	0.8	0.0260	0.3420
	1	180	1.5	0.2	0.3000	0.4	0.1124	0.1056
114	0	140	1.9	0.2	0.3732	0.8	0.0110	0.4020
	1	110	1.9	0.3	0.5598	0.8	0.0502	0.4308
115	0	250	2.5	0.1	0.2500	0.2	0.2682	0.0154
	1	250	1.9	0.2	0.3810	0.0	0.8590	0.0000
116	1	310	1.9	0.1	0.1905	0.0	0.8522	0.0000
	0	190	2.5	0.2	0.5000	0.4	0.4316	0.1562
117	1	190	2.5	0.2	0.5000	0.2	0.3434	0.0820
	0	310	2.5	0.1	0.2500	0.2	0.1682	0.0404
118	1	190	2.5	0.3	0.7500	0.4	0.3566	0.2062
	0	250	2.5	0.3	0.7500	0.8	0.0284	0.6140
119	0	190	3.1	0.2	0.6190	0.8	0.0534	0.5140
	1	310	2.5	0.2	0.5000	0.4	0.2816	0.2562
120	0	250	3.1	0.2	0.6190	0.8	0.0284	0.6140
	1	190	3.1	0.3	0.9286	0.8	0.0924	0.6606

APPENDIX G

DERIVATION OF FREIGHT STATED PREFERENCE SURVEY VARIABLES

Step 1. A given combination of T and CV can be used to determine the two parameters of a log-normal distribution as follows:

$$\ln(T) = \mu + \frac{\omega^2}{2}$$

$$\ln(CV * T) = \mu + \omega^2 + \frac{\ln[\exp[\omega^2] - 1]}{2} \tag{1}$$

where exp and ln are the exponential function and natural log. Once the two parameters were determined, the density function of the log-normal distribution was determined as follows:

$$f(x) = \frac{1}{(2\pi)^{0.5}\,\omega x} \exp\left[\frac{-(\ln x - \mu)^2}{2\omega^2}\right] \tag{2}$$

Step 2. The density function (2) was used to generate the 1st, 3rd, 5th, 7th, and 9th deciles of the log-normal distribution, T_i ($i = 1 - 5$). For example, the 1st decile was generated by solving

$$0.1 = F(T_1) \tag{3}$$

where $F(t)$ is the cumulative log-normal distribution given by

$$F(t) = \int_0^t f(u)\, du \tag{4}$$

The five deciles of the log-normal distribution, T_i ($i = 1 - 5$), form a five-point distribution of transit time. Following the study of passenger travel, a five-point distribution was used.

Step 3. The five-point distribution of transit time generated above, T_i ($i = 1 - 5$), was then used to compute the five-point distribution of schedule delays, SD_i ($i = 1 - 5$), as follows:

$$SD_i = T_d - T_i, \quad i = 1 - 5 \tag{5}$$

Besides C, T, and CV used in the stated preference survey, four variables were created from the stated preference survey for the analysis:

- S: Standard deviation of transit time in hours;
- SDE: Expected schedule delay early in hours, i.e., difference between actual arrival and desired arrival when arrival is early;
- SDL: Expected schedule delay late in hours, i.e., difference between desired arrival and actual arrival when arrival is late; and
- P_L: Probability of being late.

These variables were created with information in the stated preference survey as follows:

$$S = CV \cdot T \tag{6}$$

$$SDE = \frac{1}{5}\sum_{i=1}^{5} SD_i \cdot (K_i - 1)$$

$$SDL = \frac{1}{5}\sum_{i=1}^{5} SD_i \cdot K_i$$

$$P_L = \frac{1}{5}\sum_{i=1}^{5} K_i$$

where K_i ($i = 1, \ldots, 5$) are index functions defined as follows:

$$K_i = \begin{cases} 1 & SD_i > 0 \\ 0 & SD_i \leq 0 \end{cases} \quad (i = 1, \ldots, 5) \tag{7}$$

REFERENCES AND BIBLIOGRAPHY

Abdel-Aty, Mohamed A., Ryuichi Kitamura, Paul P. Jovanis, and Kenneth M. Vaughn (1994a) *Understanding Commuters' Attitudes, Uncertainties, and Decision-making and Their Implications for Route Choice*. Draft Research Report, PATH Research Report, MOU 56.

Abdel-Aty, Mohamed A., Ryuichi Kitamura, and Paul P. Jovanis (1994b) "Investigating the Effect of Travel Time Variability on Route Choice using Repeated-Measurement Stated Preference Data," paper presented at the 74th Annual Meeting of the Transportation Research Board.

Abdelwahab, Walid, and Michel Sargious (1992) "Modeling the Demand for Freight Transport," *Journal of Transport Economics and Policy*, January, pp. 49–70.

Abkowitz, Mark D. (1981) "An Analysis of the Commuter Departure Time Decision," *Transportation*, Vol. 10, pp. 283–297.

Abu-Eisheh, Sameer A., and Fred L. Mannering (1987) "Discrete/Continuous Analysis of Commuters' Route and Departure Time Choice," *Transportation Research Record 1138*, Transportation Research Board, National Research Council, Washington DC, pp. 27–34.

Allen, W. Bruce, Mohamed M. Mahmoud, and Douglas McNeil (1985) "The Importance of Time in Transit and Reliability of Transit Time for Shippers, Receivers, and Carriers," *Transportation Research-B*, Vol. 19B, pp. 447–456.

Bates, John (1990) "Modifying Generalized Cost to Deal with Uncertain Travel Times," paper prepared for the 17th colloquium Vervoersplanologisch, Speurwerk, Den Haag, November.

Bates, John, M. Dix, and A. May, (1987) "Travel Time Variability and its Effect on Time of Day Choice for the Journey to Work," Transportation Planning Methods, Proceedings of Seminar C, PTRC, pp. 293–311.

Bates, John, N. Shepherd, and A.I.J.M. Van der Horn (1989) "Investigating Driver Reaction to Peak Hour Surcharges," Transportation Planning Methods, Proceedings of Seminar C, PTRC, pp. 103–119.

Bates, John, and George Terzis (1992) "Surveys Involving Adaptive Stated Preference Techniques," in *Proceedings of the Conference on Survey and Statistical Computing*, ed. Westlake, A., et al., Elsevier Science Publishers B.V.

Baumol, W.J., and H.D. Vinod (1970) "An Inventory Theoretical Model of Freight Demand," *Management Science*, Vol. 16, pp. 413–421.

Ben-Akiva, Moshe, and Steven R. Lerman (1985) *Discrete Choice Analysis: Theory and Application to Travel Demand*, Cambridge Massachusetts: The MIT Press.

Benwell, M., and I.G. Black (1990) "Quantifying the Value of Uncertainty in Travel Time," Transportation Planning Methods, Proceedings of Seminar H, PTRC, pp. 259–268.

Black, I.G., and J.G. Towriss (1993) "Demand Effects of Travel Time Reliability," Centre for Logistics and Transportation, Cranfield Institute of Technology.

Bradley, Mark, Phillipa Marks, and Mark Wardman (1986) "A Summary of Four Studies into the Value of Travel Time Savings," Transportation Planning Methods, Proceedings of Seminar M, PTRC, pp. 271–285.

Bruzelius, Nils (1979) *The Value of Travel Time*, London: Croon Helm.

Chang, G., and H. Mahmassani (1988) "Travel Time Prediction and Departure Time Adjustment Behavior Dynamics in a Congested Traffic System," *Transportation Research*, Vol. 22B, No. 3, pp. 217–232.

Chang, X.B., and P.R. Stopher (1981) "Defining the Perceived Attributes of Travel Modes for Urban Work Trips," *Transportation Planning and Technology*, Vol. 7.

Constable, Gordon K., and D. Clay Whybark (1978) "The Interaction of Transportation and Inventory Decisions," *Decision Sciences*, Vol. 9, pp. 688–699.

Dillman, D.A. (1978) *Mail and Telephone Surveys: The Total Design Method*, New York: John Wiley & Sons.

Evans, R.E., and W.R. Southard (1974) "Motor Carriers' and Shippers' Perceptions of the Carrier Choice Decision," *Logistics and Transportation Review*, Vol. 10, pp. 145–147.

Foster, N. (1982) "Safety Margins in Public Transport Operations on the Leeds-Headingly Corridor," MSc dissertation, Institute of Transport Studies, University of Leeds.

Fowkes, A.S., and G. Tweddle (1988) "A Computer Guided Stated Preference Experiment for Freight Mode Choice," Transportation Planning Methods, Proceedings of Seminar D, PTRC.

Fowkes, A.S., C.A. Nash, G. Tweddle, and A.E. Whiteing (1987) "Forecasting Freight Mode Choice in G.B.," Transportation Planning Methods, Proceedings of Seminar G, PTRC.

Fowkes, A.S., C.A. Nash, and G. Tweddle (1991) "Investigating the Market for Inter-Modal Freight Technologies," *Transportation Research-A*, Vol. 25A, pp. 161–172.

Gaver, Donald P., Jr. (1968) "Headstart Strategies for Combating Congestion," *Transportation Science*, Vol. 2, pp. 172–181.

Goldman, Alfred E., and Susan Schwartz McDonald (1987) *The Group Depth Interview: Principles and Practice*, Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Golob, T.F. (1970) "Analysis of Consumer Preference for Public Transportation," General Motors Research Lab, GM 4/1037.

Gunn, H. (1991) "Research into the Value of Travel Time Savings and Losses: The Netherlands 1985–1991," Paper for the Nordic Value of Time Seminar, Helsinki, December.

Guttman, Joel M. (1979) "Uncertainty, the Value of Time, and Transport Policy," *Journal of Transport Economics and Policy*, Vol. 13, pp. 225–229.

Heggie, I.G. (1976) "A Diagnostic Survey of Urban Journey to Work Behaviour," in *Modal Choice and Value of Travel Time*, ed. by Heggie, I.G., Oxford: Oxford University Press.

Hendrickson. Chris, and Edward Plank (1984) "The Flexibility of Departure Times for Work Trips," *Transportation Research*, Vol. 18A, No. 1, pp. 25–36.

Hensher, David A. (1976) "Valuation of Commuter Travel Time Savings: an Alternative Procedure," in *Modal Choice and Value of Travel Time*, ed. by Heggie, I.G., Oxford: Oxford University Press.

Hensher, David A. (1978) "Valuation in Journey Attributes: Some Existing Empirical Evidence," in *Determinants of Travel Choice*, ed. by David A. Hensher and Quasim Dalvi. New York: Praeger, pp. 203–265.

Hensher, David A. (1994) "Stated Preference Analysis of Travel Choices: The State of Practice," *Transportation*, Vol. 21, pp. 107–133.

Hensher, David A., Frank W. Milthorpe, Nariida C. Smith, and Peter O. Barnard (1989) "Urban Tolled Roads and the Value of Travel Time Savings," *The Economic Record*, Vol. 66, No. 193, pp. 146–156.

Hensher, David A., and Truong P. Truong (1985) "Valuation of Travel Time Savings: a Direct Experimental Approach," *Journal of Transport Economics and Policy*, Vol. 19, No. 3, pp. 237–261.

HLB Decision Economics, Inc. (1994) "Measuring the Relationship between Freight Transportation Services and Industry Productivity," Progress Report prepared for NCHRP. Transportation Research Board, National Research Council, Washington, DC.

HLB Decision Economics, Inc. (1994) "Research Strategies for Improving Highway User-Cost Estimating Methodologies," *Final Report,* Transportation Research Board, National Research Council, Washington, DC, May.

Jack Faucett Associates (1991) *The Highway Economic Requirements System*, Office of Policy Development, FHWA, U.S. DOT, Washington, DC.

Jackson, Burke W., and James V. Jucker (1981) "An Empirical Study of Travel Time Variability and Travel Choice Behavior," *Transportation Science,* Vol. 16, No. 4, pp. 460–475.

Knight, Trevor E. (1974) "An Approach to the Evaluation of Changes in Travel Unreliability: A 'Safety Margin' Hypothesis," *Transportation,* Vol. 3, pp. 393–408.

Lee, N., and M.Q. Dalvi, (1969) "Variations in the Value of Travel Time," *The Manchester School*, Vol. 37, No. 3.

Levin, R.C. (1978) "Allocation in Surface Freight Transportation: Does Rate Regulation Matter?" *The Bell Journal of Economics*, Vol. 9, pp. 18–45.

Louviere, Jordan J., and George G. Woodworth (1983) "Design and Analysis of Simulated Consumer Choice or Allocation Experiments: An Approach Based on Aggregate Data," *Journal of Marketing Research,* Vol. 20, pp. 350–367.

Mahmassani, H.S., and R. Herman (1989) "Interactive Experiments for the Study of Tripmaker Behaviour Dynamics in Congested Commuting Systems," presented at the Oxford Conference on Travel Behaviour, New Developments in Dynamic and Activity-Based Approaches.

Mahmassani, H.S., and D.G. Stephan (1988) "Experimental Investigation of Route and Departure Time Choice Dynamics of Urban Commuters," *Transportation Research Record 1203*, Transportation Research Board, National Research Council, Washington, DC. pp. 69–84.

Mahmassani, H.S. and C.C. Tong (1986) "Availability of Information and Dynamics of Departure Time Choice: Experimental Investigation," *Transportation Research Record 1085*, Transportation Research Board, National Research Council, Washington, DC. pp. 33–49.

McFadden, D.A., C. Winston, and A. Boersch-Supan (1985) "Joint Estimation of Freight Transportation Decisions under Non-Random Sampling," in *Analytical Studies in Transport Economics*, A.F. Daugherty, ed. Cambridge, Mass.: Cambridge University Press, pp. 137–157

McGinnis, Michael A. (1989) "A Comparative Evaluation of Freight Transportation Choice Models," *Transportation Journal*, Winter, pp. 36–46.

McGinnis, Michael A. (1990) "The Relative Importance of Cost and Service in Freight Transportation Choice: Before and After Deregulation," *Transportation Journal*, Vol. 30, pp. 12–19.

McGinnis, Michael A., Thomas M. Corsi, and Merrill J. Roberts (1981) "A Multiple Criteria Analysis of Modal Choice," *Journal of Business Logistics*, Vol. 2, pp. 48–68.

Miklius, Walter, Kenneth L. Casavant, and Peter V. Garrod (1976) "Estimation of Demand for Transportation of Agricultural Commodities," *American Journal of Agricultural Economics*, May, pp. 217–223.

Mohring, Herbert, John Schroeter, Paitoon Wiboonchutikula (1987) "The Values of Waiting Time, Travel Time, and a Seat on a Bus," *Rand Journal of Economics*, Vol. 18, No. 1, pp. 40–56.

MVA Asia (1995) *Melbourne City Link Project Review of Stated Preference Final Report*, prepared for Financiers to the Melbourne City Link Project.

MVA (1991) "European Intermodal Freight," Unpublished report to Strategic Planning Associates and Railfreight Distribution.

MVA Consultancy and Institute for Transport Studies of the University of Leeds (ITS Leeds) (1992) *Quality of a Journey: Final Report*, prepared for the U.K. Department of Transport, Contract No. 02/C/5274.

MVA Consultancy, ITS Leeds, and Transport Studies Unit of Oxford University (1987) *The Value of Travel Time Savings: A Report of Research Undertaken for the Department of Transport*, Newbury, England: Policy Journals.

MVA and ITS Leeds (1989) "Freight," Unpublished report to Railfreight Distribution, British Railways.

Nelson, J.P. (1977), "Accessibility and the Value of Time in Commuting," *Southern Economic Journal*, Vol. 43, pp. 1321–1329.

Noland, Robert B., and Kenneth A. Small (1995) "Travel-Time Uncertainty, Departure Time Choice, and the Cost of the Morning Commutes," paper presented at the 74th Annual Meeting of the Transportation Research Board and later published as *Transportation Research Record 1493*, Transportation Research Board, National Research Council, Washington, DC. pp. 150–158.

Noland, Robert B., Kenneth A. Small, Pia Maria Koskenoja, and Xuehao Chu (1998) "Simulating Travel Reliability," *Regional Science and Urban Economics*, Vol. 28, pp. 535–564.

Ogwude, I.C. (1990) "Estimating the Modal Choice of Industrial Freight Transportation in Nigeria," *International Journal of Transport Economics*, Vol. 17, pp. 187–205.

Ogwude, I.C. (1993) "The Value of Transit Time in Industrial Freight Transportation in Nigeria," *International Journal of Transport Economics*, Vol. 20, pp. 325–337.

Oum, Tae Hoon (1979) "A Cross Sectional Study of Freight Transport Demand and Rail-Truck Competition in Canada," *The Bell Journal of Economics*, Vol. 10, pp. 463–482.

Pells, S. (1987) "The Evaluation of Reductions in the Variability of Travel Times to Work," Transportation Planning Methods, Proceedings of Seminar C, PTRC, pp. 313–325.

Polak, John (1987) "Travel Time Variability and Departure Time Choice: A Utility Theoretic Approach," Transport Studies Group, Discussion Paper No. 15, Polytechnic of Central London.

Prashker, Joseph N. (1979) "Direct Analysis of the Perceived Importance of Attributes of Reliability of Travel Modes in Urban Travel," *Transportation*, Vol. 8, pp. 329–346.

Paine, F.T., et al. (1969) "Consumer Attitudes Towards Auto and Public Transportation Alternatives," *Journal of Applied Psychology*, Vol. 53, No. 6.

Quarmby, D.A. (1967) "Choice of Travel Mode for the Journey to Work: Some Findings," *Journal of Transport Economics and Policy*, Vol. 1, pp. 1–42.

Quarmby, D.A. (1989) "Developments in the Retail Market and Their Effect on Freight Distribution," *Journal of Transport Economic and Policy*, January, pp. 75–87.

Rao, Kant, and William L., Grenoble, IV (1991) "Modeling the effects of traffic congestion on JIT," *International Journal of Physical Distribution & Logistics Management*, Vol. 21, pp. 3–9.

Richardson, A.J., and A.P. Cuddon (1994) *Melbourne City Link Project: Stated Preference Survey Methodology.*

Roberts, P.O., and K. Wang (1979) "Predicting Freight Transport Level of Service Attributes," *Report No. 79-17*, Center for Transportation Studies, MIT, Cambridge, Mass.

Senna, Luiz A.D.S. (1994) "The Influence of Travel Time Variability on the Value of Time," *Transportation*, Vol. 21, pp. 203–228.

Sheffi, Yosef, Babak Eskandari, and Haris N. Koutsopolous (1988) "Transportation Mode Choice Based on Total Logistics Costs," *Journal of Business Logistics*, Vol. 9, pp. 137–152.

Small, Kenneth A. (1982) "The Scheduling of Consumer Activities: Work Trips," *American Economic Review*, Vol. 72, pp. 467–479.

Small, Kenneth A. (1992) *Urban Transportation Economics*, Harwood Academic Publishers, Chur, Switzerland.

Small, Kenneth A., Robert B. Noland, and Pia Maria Koskenoja (1995) "Socio-economic Attributes and Impacts of Travel Reliability: A Stated Preference Approach," Draft PATH Report, MOU-117, California Partners for Advanced Transit and Highways.

Stopher, Peter R. (1976) "Derivation of Values of Time for Travel Demand Models," *Transportation Research Record 587*, Transportation Research Board, National Research Council, Washington, DC, pp. 12–18.

Terzis, George, Geoff Copley, and John Bates (1992) "Seeking New Business Opportunities for Trainload Freight."

Train, Kenneth (1976) "Work Trip Mode Split Models: An Empirical Exploration of Estimate Sensitivity to Model and Data Specification," *Working Paper No. 7602*, Urban Travel Demand Forecasting Project, Institute of Transportation Studies, University of California, Berkeley.

Tyworth, John E. (1992) "Modeling Transportation-Inventory Trade-Offs in a Stochastic Setting," *Journal of Business Logistics*, Vol. 13, pp. 97–121.

Vinson, Charles E. (1972), "The Cost of Ignoring Lead Time Uncertainty in Inventory Theory," *Decision Sciences*, Vol. 3, pp. 87–105.

Ward, V.M., J.T. Bertrand, and L.F. Brown (1991) "The Comparability of Focus Group and Survey Results—3 Case Studies," *Evaluation Review*, Vol. 15, pp. 266–283.

Waters, II, W.G. (1992) "Values of Travel Time Savings and the Link with Income," Paper prepared for presentation at the Annual Meeting of the Canadian Transportation Research Forum, Banff, Alberta.

Watson, Peter L., James C. Hartwig, and William E. Linton (1974) "Factors Influencing Shipping Mode Choice For Intercity Freight: A Disaggregate Approach," *Transportation Research Forum*, Vol. 15, pp. 138–144.

Wilson, F.R., B.G. Bisson, and K.B. Kobia (1986) "Factors that Determine Mode Choice in the Transportation of General Freight," *Transportation Research Record 1061*, Transportation Research Board, National Research Council, Washington, DC., pp. 26–31.

Winston, Clifford (1981) "A Disaggregate Model of the Demand for Intercity Freight Transportation," *Econometrica*, Vol. 49, pp. 981–1006.

Winston, Clifford (1983) "The Demand for Freight Transportation Models and Applications," *Transportation Research-A*, Vol. 17A, pp. 419–427.

Zlatoper, Thomas J., and Ziona Austrian (1989) "Freight Transportation Demand: A Survey of Recent Econometric Studies," *Transportation*, Vol. 16, pp. 27–46.

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The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation